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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 826

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. — PROFESSIONAL PAPER. — August 10, 1920

GENERIC CLASSIFICATION OF THE HEMIPTEROUS FAMILY APHIDIDAE.[1]

By A. C. Baker,
Entomologist, Deciduous Fruit Insect Investigations.

CONTENTS.

Probably no group of insects has received more attention at the hands of economic entomologists than aphids, or plant-lice. Their interesting and often complicated biologies have attracted the attention of investigators, not only among entomologists, but among workers in the larger fields of zoology and general biology. While a large amount of work on the life histories and biologies of aphids has been done, corresponding progress in their classification has not been made. This is probably due to several causes, such as the lack of correlation of biologic and taxonomic facts, and the failure of aphidologists to consider sufficiently the results of the work of others.

On account of the great economic importance of aphids and the necessity of their study in the development of control measures, the lack of knowledge concerning their systematic relationships results in much confusion. Some biologic workers, in fact, do not now attempt to give the name of the species being studied on account of the difficulty experienced in securing correct determinations.

[1] This paper is the first of a series treating the Aphididae. It will be followed by others dealing with the economic importance, biologies, and relationships of species in the different genera.

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The present work was undertaken in the hope of remedying such a condition to some extent at least. The genera of the world have been studied. Many workers have lent material and the large collections of the National Museum and Bureau of Entomology have been drawn upon. In the National Museum collection a large percentage of types has been available. To the study of preserved material have been added embryological, anatomical, and biological investigations that a better understanding of the natural relationships might be gained.

Besides many aphidologists in this country and abroad, who have given helpful suggestions and many of whom have read and criticized the manuscript, the writer is indebted to Dr. A. L. Quaintance, of the Bureau of Entomology, for the facilities for conducting many of the biological investigations which to a large extent have laid the foundation for the systematic treatment here given.

Superfamily APHIDOIDEA.

There appear to be two distinct families in the superfamily Aphidoidea. These are the Aphididae and the Phylloxeridae. The present paper deals only with the Aphididae.

Members of the Phylloxeridae differ markedly from forms belonging to the Aphididae. In the first place their biologies are quite different in that parthenogenetic oviparous forms occur during the summer. In the Aphididae only the sexed females which are produced in the fall are normally oviparous.

In structure the two families are separated at once by the formation of the stigma of the forewing. The wing itself seems very little different in an Adelges or Phylloxera from that in some of the specialized genera of the Aphididae. An examination of the freshly emerged wing, however, as has been pointed out by Dr. Patch, shows that the stigma in the Phylloxeridae is formed by the radial sector and the stigmal vein is the media. In the Aphididae, on the other hand, the stigma is formed by radius $_1$ and the stigmal vein is the radial sector. The two families may thus be separated as follows:

KEY TO THE FAMILIES OF THE APHIDOIDEA.

Summer parthenogenetic oviparous forms produced: Stigma formed by the radial sector .... PHYLLOXERIDAE.

Only sexual oviparous forms produced: Stigma formed by radius$_1$ .... APHIDIDAE.

A word of explanation in regard to the name Phylloxeridae may be necessary. The genus Chermes was erected by Linnaeus in 1758 and in 1862 was replaced by Psylla Geoffroy. For this genus *Chermes ficus* L. was set as type by Lamarck in 1801. *Ficus*, therefore, becomes *ipso facto* the type of Chermes, and Chermidae the family name of the "jumping plant-lice." The family name for the aphidoidean group, therefore, is derived from the genus Phylloxera Boyer (1834).

PHYLOGENY OF THE APHIDIDAE.

In many published classifications of the Aphididae those groups which according to the writer's conception are the most specialized have been placed as the most primitive. This is the case with those

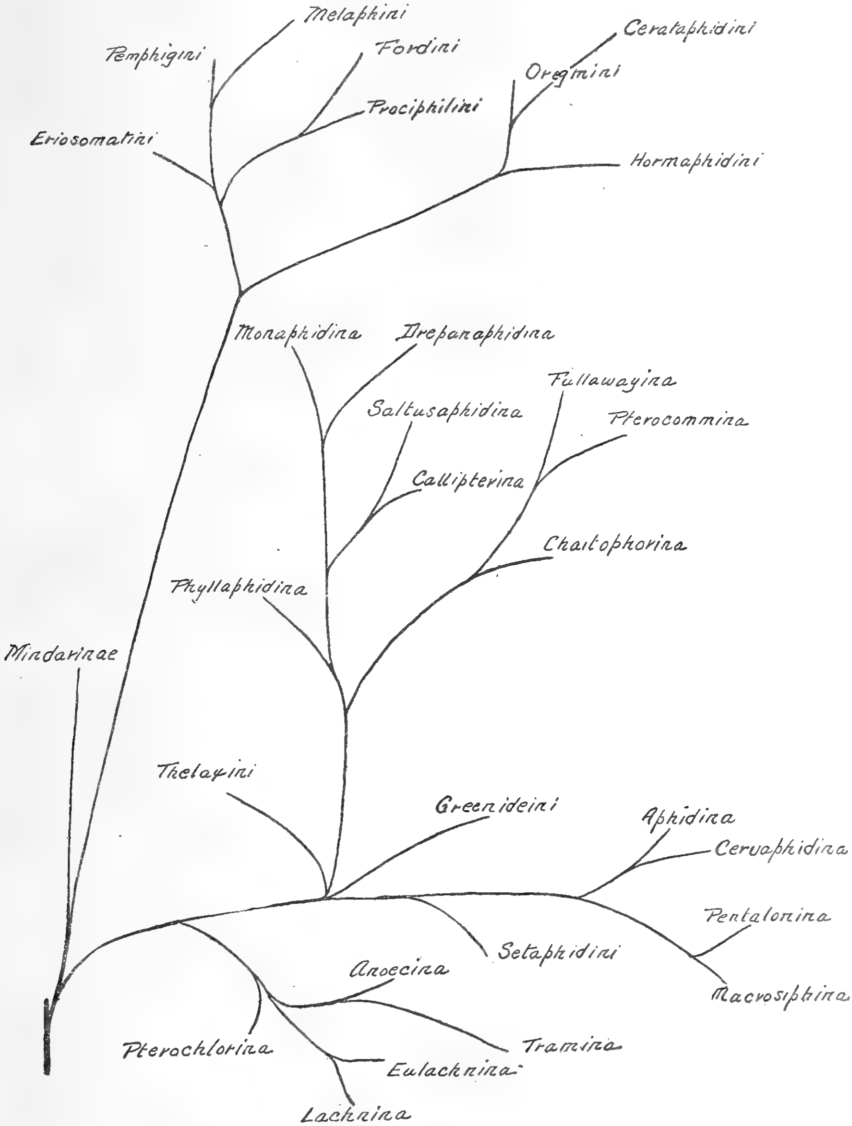

FIG. 1.—Phylogeny of the hemipterous family Aphididae.

insects forming in the present classification the Eriosomatinae and the Hormaphidinae.

A study of the anatomy and the biology of aphids makes it evident that there are three main groups of living forms for which subfamily names are here used: Aphidinae, Eriosomatinae, and Hormaphidinae. Besides these there is the one species, in some ways a relic of the past, forming the Mindarinae.

As will be seen by the diagram (fig. 1), the Aphidinae is considered the most primitive subfamily of the three main groups. This is substantiated by the habits of the insects, by the structure of the wings, beak, etc., and by the sexual forms.

Practically all of these insects are foliage or twig feeders. They live, as a rule, in colonies and have not developed any very special methods of life, such as highly complex gall formation. With the exception of the Mindarinae the most primitive wing structure occurring in the family is met with here. The media is most commonly twice branched throughout the subfamily and even in the Mindarinae there is more of a reduction than this. The antennæ are of six segments, the largest number found in the family, and the sensoria are simpler in nature than those met with in the other two large subfamilies. The beak in the Lachnini shows also a primitive condition in its segmentation.

The sexual forms are most primitive in the Aphidinae. Winged sexes often occur, at least the males are very commonly winged. Both sexes still retain their beaks and feed on their hosts in the same way as do the other forms, and the ovaries of the female develop normally, and she produces several eggs.

When the phylogeny of this subfamily is studied, there becomes evident the primitive character retained by the Lachnini. In these forms the beak structure and the nature of the antennæ and cornicles point to a primitive condition. The sexes, too, indicate this, though not markedly more than in other tribes. But the fact that these forms are mostly conifer feeders should not be overlooked. It is the opinion of the writer that this is a primitive habit. The Lachnus branch, therefore, may be considered the lowest branch of the Aphidinae. If the wings of fossil aphids be examined it will be seen that by far the greater number of them possess a wing structure quite different from that of our living forms. The radial sector arises back of the stigma, which is usually very long and narrow. This character is retained probably only in the Mindarinae. It is evident, then, that during the development of the present Aphidinae this vein migrated toward the tip of the wing until it came to stand either in the middle of the stigma or near its tip. On one line of this migration is the Lachnina wherein the vein has reached nearly to the tip of the wing and become short and straight. The remaining characters apart from the wings have in these forms remained quite primitive. The subtribe Eulachnina is evidently a more specialized group on this same line of development, for it possesses the same type of wing. Therefore this subtribe is considered quite closely related to the subtribe Lachnina but differing from it in specialization of body form, cornicles, and eyes. The other subtribes of the Lachnini have quite a different wing structure. While the radial sector has changed its position considerably from that found in the fossils it has not reached the tip of the stigma and is not straight, but much curved. In this regard, therefore, the Pterochlorina is perhaps the most primitive subtribe in the Lachnini, although in many respects it is specialized. On the other hand there are two highly specialized subtribes, the Anoecina and the Tramina. It is usually the custom to place the Anoecina with the Pemphigina. Its relations, however, are here. The adult forms are very similar indeed to the lachnids. The sexual forms, on the other hand, are small and apterous and suggestive of the sexes of the Eriosomatinae, and there is considerable ground for placing the Anoecina there. These sexual forms, however, seem to differ quite distinctly from those of the Eriosomatinae, which are beakless and the oviparous female of which never develops more than one egg. The development of the stigma shows quite an extreme modification from the long, narrow, primitive stigma.

Near this same line of development is the rather highly specialized subtribe Tramina. The most marked character of this subtribe is the extreme modification of the hind tarsi. In considering only the genus Trama it might be thought that the tribe should belong with the Eriosomatinae. The species *troglodytes* has often been figured with cornicles in the apterous form. Specimens from Mordwilko and Schouteden determined as this species lack them and the writer therefore considers Trama as the most specialized genus in the subtribe. Another genus represented by *radicis* Kalt. shows cornicles very large and of a typical Lachnus character. Through this genus, therefore, the subtribe can be placed at once with its relatives in the Lachnini. Apart from the peculiar tibial character this genus is very lachnid-like.

The next branch from the Aphidinae is the Callipterus branch, which may be considered as arising somewhat later than the Lachnus branch. From this offshoot soon after it arose and before the present genera of the Callipterini appeared the Thelaxini separated.

This tribe, the old Vacuini, also has usually been placed with the Eriosomatinae. There are some resemblances, it is true; only one egg, for instance, is usually laid by the sexual female. But this is not always the case, for, according to Buckton, more than one egg is sometimes laid. Such a condition shows that the one egg habit is of much more recent development than in the Eriosomatinae. Moreover, the sexual female is very different in structure. She is not the degenerate, beakless, nonfeeding individual of the Eriosomatinae, but feeds upon the leaf like the viviparous forms. Moreover, in external structure these insects resemble certain ones of the Callipterini, to such an extent, indeed, that Davidson has described one of these forms as a Chaitophorus. Certain of the structures met with in these forms resemble those found in the Hormaphidinae and on these structures the tribe might be placed there. The writer believes, however, that the true affinities of the tribe are shown by comparison with the Phyllaphidina. It will be seen at a glance that there is a very close resemblance in all main characters. But the sexual forms are different, although not so strikingly different as would appear at first. In the Phyllaphidina both winged and wingless ovipara and as a rule winged males occur. But in some species (*quercifoliae*) intermediate and apterous males also occur. It is not a very long call, therefore, from the apterous males and females of the Phyllaphidina to the apterous sexes of the Thelaxini. But the habit of egg laying met with in this last tribe shows that it has been on this course of development longer than has the Phyllaphidina. The group is therefore considered as a tribe which has separated somewhat earlier and yet has paralleled in some ways certain characters of the Phyllaphidina.

Continuing with the Callipterus branch we find two somewhat similar lines of development, the one represented by the Callipterina and the other represented by the Chaitophorina. Both are similar in many regards, but are quite different in the armature, particularly of the antennæ.

The first subtribe separating from that offshoot represented by the Callipterina is the Phyllaphidina. This seems evident from the fact that the oviparous forms of some species are yet alate, a primitive condition found very seldom in the Aphididae. The next offshoot resulted in the Callipterina where the oviparous forms are apterous, the cornicles of moderate development, and the wing veins usually not reduced. From this offshoot the Saltusaphidina evidently arose. This little subtribe is closely related to the Callipterina in many ways, but there are some new developments. In the first place the power of leaping has become developed by the enlarging of the femora. Secondly, both the sexual forms have lost their wings, which the male usually retains in the Callipterina. One of the most important points, however, is the fact that in the Saltusaphidina the ocular tubercles which represent the retained larval eyes are absent, whereas they are quite conspicuous in the Callipterina.

On this same Callipterus branch, but somewhat more specialized than the Callipterina, are two subtribes. These have specialized in opposite directions, the one toward the elimination of the cornicles and the other toward the development of them. The first subtribe, the Monaphidina, lacks cornicles above. The second of these two, the Drepanaphidina, possesses them in varying degrees. In this last subtribe the males are winged, and the females have developed an extremely long, narrow ovipositor.

Coming now to that line represented by Chaitophorus, the Chaitophorina are found to be the most generalized, corresponding quite closely with the Callipterina. In this subtribe males are winged as a rule, but sometimes in the same species they are intermediate or apterous. Arising from the same branch with the Chaitophorina are two subtribes specialized in different directions, like the subtribes of Callipterus. The first, Fullawayina, lacks cornicles entirely, whereas the Pterocommina has developed them in varying degrees, as has the Drepanaphidina. This concludes the subtribes of the Callipterus branch.

In connection with these insects the tribe Greenideini should be considered. The cornicles of the primitive aphids were evidently small, somewhat rounded or conical, and armed with hairs. In the Greenideini the insects have very long cylindric or somewhat swollen cornicles which are thickly covered with prominent hairs. No such well-developed cornicles are met with in any of the other tribes of the family, although they are approached in the Macrosiphina. In this latter subtribe species occasionally occur which show a few short hairs on the cornicles. It seems evident then that the Greenideini separated from the Aphidinae before the hairs of the cornicles disappeared. This was evidently more recent than the development of the tribe Lachnini which possesses a much more primitive cornicle. At about the same time that the ancestors of the Callipterini separated from the Aphidinae, other forms probably separated and more or less paralleled in some ways the ancestors of the Macrosiphina, but unlike them carried the hairs of the cornicles. They thus resulted in forms with very long cornicles similar to those of the Macrosiphina but armed with long hairs. In other characters, too, they of course differ, particularly in regard to the cauda.

In considering the further development of the Aphidinae, a more or less distinct development of the cornicles and antennal tubercles is found. There are thus two types which separate themselves, represented by Aphis and Macrosiphum respectively. These may be considered as leaving the aphid line at about the same time after the development of prominent cornicles. There are, consequently, two subtribes, the Aphidina and the Macrosiphina. The Cervaphidina represents a group of insects armed with long, somewhat cylindric cornicles, and very prominent spinelike protuberances. The number of antennal segments is somewhat reduced, as is also the wing venation. It seems evident then that this is a subtribe on somewhat the same line of development as the Aphidina but developing these specialized spines during the same period in which the wings and antennæ have become reduced. Still another subtribe, the Pentalonina, shows a very peculiar wing venation. This is not so much a primitive wing as a more specialized one. It is placed, therefore, as one of the highest subtribes of the Aphidini.

There remains yet for discussion the tribe Setaphidini. This, it seems evident, belongs with the Aphidinae. In regard to the antennæ and the wings it is quite highly specialized but in regard to the cornicles, cauda, and anal plate this statement can not be made. The natural position of this tribe is somewhat doubtful. Its ancestors evidently separated from the aphidian line before the prominent cornicles of the Aphidina, Macrosiphina, etc., appeared and yet the species are more specialized in many ways than are members of those subtribes. It would appear that the lines separated after that of the Greenideini, for the cornicles are not hairy. Yet this separation must have taken place a considerable time before that of the Aphidina and Macrosiphina. The tribe is placed, therefore, as indicated in the diagram (fig. 1).

The subfamilies, other than the Aphidinae, include the most specialized members of the family. By far the most primitive of these subfamilies is the Mindarinae. This subfamily, as has been indicated, is a remnant from the past, giving some idea of the ancestors of the Eriosomatinae and the Hormaphidinae. The wing structure is particularly worthy of study. The wing of no other living aphid is like it, but this peculiar structure is abundantly met with in fossil forms. The media, it is true, is more reduced than in certain members of the Aphidinae, but this is of very little importance as compared with the wing's peculiar structure. The form also feeds upon conifers and this is undoubtedly a primitive habit. The cauda and anal plate are unlike those met with either in the Eriosomatinae or the Hormaphidinae.

The sexual forms are interesting. They have become sufficiently specialized toward the Eriosomatinae to have lost the wings, but they retain the beak, at least in most individuals, and feed. The ovaries of the oviparous female also are developed so that a number of eggs are laid.

The two remaining subfamilies are the most highly specialized of all aphids.

The Eriosomatinae are in many ways more specialized than the Hormaphidinae, but in other ways they are more primitive. The whole Eriosoma line separates at once on the sexual forms. These are small, apterous, and beakless. Throughout their life they take no nourishment, and the ovaries of the oviparous female become atrophied, so that only one develops and of the eggs therein only one reaches maturity. The most primitive tribe on this line is the Eriosomatini. The forms of this tribe are not as a rule distinct gall formers. They possess rather prominent cornicles and have developed special wax glands. They live as a rule upon deciduous trees, the summer forms of many species alternating upon the roots of plants.

More specialized than the Eriosomatini are the Pemphigini, which, however, are very similar to the former in many respects. These are distinct and true gall formers on deciduous trees. For part of the year they are usually altogether closed within the gall. Wax secretion is common and the cornicles are present, but reduced to mere rings.

The Melaphini are closely related to the Pemphigini and are gall formers like them. These forms, however, have lost entirely the cornicles which are usually still retained in the Pemphigini.

A somewhat different specialization is met with in the Prociphilini. Here wax secretion has developed at the expense of the cornicles so that these organs are absent, at least in nearly all the forms of the species. Large wax plates have taken their places. The species are not true gall formers, but live upon foliage which they cause to roll or crumple into a pseudogall. Development along this line is also present in the next tribe, the Fordini.

Here the cornicles are also absent, being replaced by large wax glands, but the species are nearly all root feeders and are usually associated with ants, often living with them in their nests. This tribe may be considered the most specialized of all the Eriosomatinae.

The same specialization in the sexual forms has not occured in the Hormaphidinae. They are small and apterous, it is true, but they possess beaks, they feed, and the oviparous female lays more than one egg. In one regard, however, these insects are more specialized. Many of them have developed a pecular aleyrodiform stage, which is quite different from anything occuring elsewhere in the family. Along with this development peculiar wax glands have made their appearance so that some of these forms look very much like aleyrodids and are indeed often mistaken for them.

The most primitive tribe here is the Oregmini, which, although it possesses many of the other characters met with in these forms, lacks the aleyrodiform stage. These insects possess quite distinct cornicles.

Closely related to the Oregmini is the Cerataphidini. These insects likewise possess cornicles and in several ways suggest the Oregmini, but they have developed a distinct aleyrodiform stage and in this regard are much more advanced than the members of that tribe.

Lastly, and perhaps most specialized of all, are the Hormaphidini. These insects are curious gall formers, not only on their primary host, but often on their secondary one as well. They lack cornicles and have developed aleyrodiform generations and wax secreting structures. In many ways the specialization of these insects is most remarkable.

KEY TO THE SUBFAMILIES OF THE APHIDIDAE.

1. Sexual forms small with functioning mouth parts absent. Oviparous female with all the egg tubes present or indicated in the embryo but the adult possessing only one tube and maturing one cell so that one egg only is laid. Cornicles much reduced or absent. Wax glands abundantly developed. Wing veins usually reduced. Antennal sensoria prominent.......ERIOSOMATINAE.
   Sexual forms with functioning mouth parts. Nearly all the ovarian tubes developed in the adult oviparous female....... 2.
2. Radial sector of forewing inserted mesad of the stigma. Sexes small. Oviparous female laying several eggs.......MINDARINAE.
   Radial sector not so inserted but arising from the stigma....... 3.
3. Forms usually gall makers. Wing veins much reduced so that the media is usually simple. Wax glands usual. Antennal sensoria annular. Aleyrodiform stages common. Sexes wingless as a rule and small..HORMAPHIDINAE.
   Forms not usually gall makers. Wing veins often not reduced. Wax glands not abundant. Antennal sensoria oval or subcircular. Aleyrodiform stages rare. Cornicles often little reduced. Winged males common. APHIDINAE.

Subfamily I, APHIDINAE.

The subfamily Aphidinae contains many of the most primitive insects in the family. Indeed, with the exception of the Mindarinae the subfamily may be considered as by far the most primitive.

The oviparous female, in all the tribes, develops the ovaries in a normal way and lays several eggs. An exception to this, however, is the Thelaxini, but here two or more eggs are sometimes laid. The males may be either alate, apterous, or intermediate, and in many species which possess the migratory instinct they are often produced on quite a different food plant from the oviparous form. The stem mothers are in practically all cases apterous, but the remaining generations throughout the year may or may not be winged. In many species a larger percentage of winged forms occurs in certain generations and a larger percentage of apterous forms in others. In some species, however, this does not appear to be the case. In certain of the Callipterini practically all of the viviparous forms other than stem mothers are winged.

The insects are mainly foliage feeders, but they also attack the stems and roots. They occur both upon woody plants and herbs. Their feeding may have little apparent effect upon the host or it may cause distortions or pseudogalls. Some species are particularly injurious to their hosts and when these are economic plants cause much loss.

Great variation is met with amongst the members of the subfamily. The antennæ are rather long and slender and as a rule are armed with subcircular sensoria. In most of the forms the sixth segment possesses an elongate narrow unguis, which in some of the Callipterini and Aphidini is remarkably developed. In the more primitive groups, however, this is short and thumb-like. The head of the apterous form differs much from that seen in the Eriosomatinae, in that true compound eyes are present and often very prominent, and the small larval eyes are seen as ocular tubercles. It is noteworthy that in the Eriosomatinae the alate forms possess distinct compound eyes but the apterous forms have lost them. The wings are in general quite similar throughout the family in regard to the venation. In color, shape, and location of the veins there is often considerable difference. Moreover, there are a few genera amongst the different tribes which show abnormal wing form, of which genera Microparsus is a good example. In the typical forms of this subfamily the media of the fore wing is twice branched, but it is very commonly branched only once and it is rarely simple.

The cornicles show remarkable variation. In some forms of the Callipterini they are short and slightly swollen at the base, in the Lachnini they are low broad cones, whereas in the Greenideini they are cylindrical and sometimes longer than the body. Between these extremes every gradation occurs. The cornicles may be straight or they may be swollen to a greater or less degree. Practically all forms eject a colored wax from these organs when disturbed.

The cauda shows almost as much variation as the cornicles, sometimes being short and rounded, in other cases elongate, spatulate, or conical, and in others distinctly knobbed. Variation also is met with in the anal plate, though this usually is rounded, In the Callipterini, however, it is often bilobed.

The tribes of the subfamily may be separated as follows:

KEY TO THE TRIBES OF THE APHIDINAE.

1. Cornicles situated on broad flat cones.......... 2.
   Cornicles truncate, or more or less elongate.......... 3.
2. Cornicles and antennæ hairy. Antennæ with the unguis short and thick.......... LACHNINI.
   Cornicles and antennæ not hairy. Antennæ with the unguis long and slender.......... SETAPHIDINI.
3. Cornicles clothed with long hairs.......... GREENIDEINI.
   Cornicles never with long hairs.......... 4.
4. Thorax of alate form with the lobes not prominently developed; oviparous form small, often laying one egg. Large wax plates present.......... THELAXINI.
   Thorax of alate form with the lobes prominently developed; oviparous female laying several eggs. Large wax plates usually absent.......... 5.
5. Cornicles truncate or elongate; when elongate the cauda knobbed, and the anal plate bilobed, or the antennæ prominently hairy.......... CALLIPTERINI.
   Cornicles not truncate, usually elongate. Cauda never knobbed. Antennæ with only a few spinelike hairs.......... APHIDINI.

Tribe LACHNINI.

The tribe Lachnini is the most primitive of all living aphids, with the exception of the Mindarinae. The genus Mindarus shows in its wing structure characters more primitive than any of the Lachnini, but in other characters such as those of the beak, cornicles, cauda, sensory structures, etc., the Lachnini are very primitive insects. In examining the fossil wings it is to be noted that the radial sector is situated back of the stigma. In practically all living aphids, with the exception of Mindarus, this vein has migrated toward the tip of the wing. In primitive forms the stigma is long and narrow, whereas in most living forms it has become more or less compact. In the subtribe Lachnina the radial sector has become a very short, straight vein almost at the tip of the wing. This shows that the Lachnina are evidently more advanced than the Pterochlorina in which the radial sector is somewhat curved and situated near the middle of the stigma. The subtribe Eulachnina is considerably specialized, as indicated by the eyes, the shape of the body, and the cornicles. It is, however, as closely related to the Lachnina as are any of the other tribes, as will be seen from the formation of the wing. The Anoecina in the typical genus shows a wing with a short blocky stigma, a condition quite different from that seen in the Lachnina, and the radial sector is here curved. (In Nippolachnus, however, the stigma is still long and straight.) Moreover, the sexual forms are more specialized, being apterous in both cases. Anoecia, therefore, is somewhat removed from Lachnus. The genus Trama is considerably specialized, in that it lacks cornicles in the apterous form. It is, however, related to Lachnus through Neotrama with small cornicles, and Protrama with large hairy cornicles.

The rostrum in the Lachnini is in many species five-segmented, a primitive character most marked in this group. The freshly emerged wing of a lachnid shows that M_1, M_2, and M_{3+4} are the veins represented when the media is twice branched, and that in some species no vein is formed about M_2. The cubitus and first and second anal are present in the forewing. As in other Aphididae, however, no vein forms about the second anal. The radial sector is in Lachnus a short, straight trachea and a prominent vein forms about it. The stigma, as in all members of the family, is formed by $radius_1$. In the hindwing both media and cubitus are present and form distinct veins.

The antennæ of the Lachnini are six-segmented with a short unguis. They are usually armed with oval or subcircular sensoria and prominent hairs. In fact, the entire body of the insect is hairy.

The cornicles are characteristic. They are situated on distinct cones which are constricted before the somewhat flanged opening which is not situated over the center of the cone. The cones are armed with hairs. Some specialized forms have small cornicles or none at all. Wax-secreting structures, but no distinct gland areas, are present in this tribe and a coating of fine wax is often found over the entire insect, including the appendages. This is true of the oviparous forms, as well as of the viviparous ones.

The cauda and anal plate are here rounded, never developed into elongate structures as in some of the other tribes of the subfamily. The sexual forms are nearly as unspecialized as the viviparous ones. Both sexes possess a distinct rostrum and take food. The males in the typical subtribes are winged. The females are apterous, but the ovaries are developed and several eggs are laid by each individual.

KEY TO THE SUBTRIBES OF THE LACHNINI.

1. Radial sector of fore wings curved and of moderate length................ 2.
   Radial sector of fore wings short and straight, situated near the tip of the wing.. 4.
2. Hind tarsi extremely elongate, head divided, wing venation usually faint. TRAMINA.
   Hind tarsi normal.. 3.
3. Stigma short and thick, sexes both apterous ....ANOECINA.
   Stigma elongate, males often winged........................PTEROCHLORINA.
4. Form elongate and very narrow; antennæ with bristles, cornicles not hairy; eyes without ocular tubercles.................................EULACHNINA.
   Form not elongate; cornicles on hairy cones; eyes with ocular tubercles..LACHNINA.

Subtribe ANOECINA.

The subtribe Anoecina is suggestive of the Tramina, but none of the forms are as specialized as some of the genera of that subtribe. The typical genus is quite distinctive in the short rounded stigma and in the sexual forms. The genus Nippolachnus, however, has a stigma quite Lachnus-like in appearance. Only two genera are known at present.

KEY TO THE GENERA OF THE ANOECINA.

1. Head not divided; eyes with prominent ocular tubercles; stigma of wing short and rounded...Anoecia.
2. Head divided; eyes without ocular tubercles; stigma long and straight. Nippolachnus.

Genus ANOECIA Koch.

Plate I, A–F, I.

1857. *Anoecia* Koch, Die Pflanzenlaüse Aphiden, p. 275.

Characters.—Head not divided, front somewhat rounded. Eyes prominent but not distinctly set off from the head. Antennæ of six segments, armed with subcircular or oval or elongate sensoria and covered with hairs. Fore wings with the media once branched. Stigma short and thick. Hind wings with both media and cubitus present. Cornicles situated on broad hairy cones. Cauda and anal plate somewhat rounded.

Spring forms free, living in colonies; summer forms often subterranean. Sexes small and apterous, possessing beaks and feeding. Oviparous female laying one or more than one egg.

Type (monotypical), *Aphis corni* Fab.

Genus NIPPOLACHNUS Matsumura.

Plate I, G, H, J, K.

1917. *Nippolachnus* Matsumura, Journ. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 382.

This genus is closely related to Anoecia Koch and yet it retains many Lachnus characters which are not present in Anoecia. It is separated from that genus by several important points. The head is distinctly divided as it is not in Anoecia. The stigma is long and Lachnus-like and the eyes have not the small prominent ocular tubercles of Anoecia, but are rounded on their posterior margins.

Characters.—Antennæ of six segments, armed with prominent protruding sensoria and many hairs; head divided; eyes without prominent ocular tubercles. Wings with the media once branched, the stigma rather long and narrow. Cornicles on large broad cones entirely covered with hairs.

Spring forms free, migrating in summer to alternate hosts. Sexes small, males winged.

Type (fixed by Matsumura, 1917), *Nippolachnus piri* Mats.

Subtribe EULACHNINA.

The subtribe Eulachnina is related to the Lachnina quite closely, as can be seen by the wing structure where the radial sector is a straight, short vein extending across the tip of the wing. The media also is faintly indicated. In the other branch of the tribe in which the Anoecina and Tramina are found, the radial sector is curved as it is in Aphidina, etc. Members of the Eulachnina may, however, be separated at once from the Lachnina on the elongate, narrow shape of the body, the abruptly rounded cauda, the character of the cornicles, and the absence of ocular tubercles upon the eyes. The subtribe is evidently quite specialized as compared to the Lachnina.

Characters.—Eyes large and set off from the head; ocular tubercles not evident; antennæ slender, armed with bristles or spines, not slender hairs. Cornicles shallow, not on distinct hairy cones. Cauda abruptly rounded. Body very elongate and slender, scarcely wider than the head.

KEY TO THE GENERA OF THE EULACHNINA.

1. Antennæ of five segments, armed with minute bristles.................Essigella.
   Antennæ of six segments.. 2.
2. Media once branched, antennæ with long stout spines.................Eulachnus.
   Media twice branched...Todolachnus.

Genus ESSIGELLA Del Guercio.

Plate I, S-Y.

1909. *Essigella* Del Guercio, Rivista Patol. Vegetale, n. s., v. 3, p. 329.

The genus Essigella is quite similar to Eulachnus with the exception of the antennæ.

Characters.—Head with large outstanding eyes, very much broader than long. Antennæ of five segments, imbricated, armed only with a few minute bristles. Fore wings with the media faintly indicated, once branched, hind wings with both media and cubitus present. Cornicles chitinized rings situated close to the body, no hairy cones present. Cauda rounded. Body elongate and narrow.

Type (monotypical), *Lachnus californicus* Essig.

Genus EULACHNUS Del Guercio.

Plate I, L–R.

?1853. *Cinaria* Curtis, British Entomology, v. 12, section 576.
1909. *Eulachnus* Del Guercio, Rivista Patol. Vegetale, n. s., v. 3, p. 329.
1915. *Protolachnus* Theobald, Bull. Ent. Res., v. 6, p. 145.

Del Guercio erected the genus Eulachnus without setting a type, but Wilson [1] has indicated *agilis* Kalt. as the type. Apparently, therefore, the genus must be based upon that species. Theobald's genus was based on his *tuberculostemmata*, a species in which the characters are the same. Cinaria was erected with *pini* L. as type, but this was questioned.

Characters.—Head divided, eyes rather large and outstanding; antennæ of six segments, armed with long stout bristles. Fore wings with the media faintly indicated and once branched; hind wings with both media and cubitus present but faint; cornicles minute rings, not situated on hairy cones. Cauda abruptly rounded. Body elongate and narrow.

Type (fixed by Wilson, 1911), *Lachnus agilis* Kalt.

Genus TODOLACHNUS Matsumura.

1917. *Todolachnus* Matsumura, Jour. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 381.

The writer has been unable to study the type of this genus, but from the description given it seems to represent a genus belonging here and having a twice-branched media. The description of the cornicles as "wart-like, not broader at base" would indicate its affinities here, also the words "body long, nearly parallel on the lateral sides."

Type (fixed by Matsumura, 1917), *Todolachnus abietis* Mats.

Subtribe LACHNINA.

The members of the subtribe Lachnina may be separated from those of other subtribes with the exception of the Eulachnina by the character of the venation. The radial sector here has almost reached the tip of the wing and become a short straight vein. The genera may be separated as follows:

KEY TO THE GENERA OF THE LACHNINA.

1. Media of fore wings twice branched........Dilachnus.
   Media not twice branched........2.
2. Media once branched........3.
   Media simple........Unilachnus.
3. Labium lance-like........Lachnus.
   Labium obtuse........Schizolachnus.

Genus LACHNUS Burmeister.

1835. *Lachnus* Burmeister, Handbuch der Ent., v. 2, pt. 1, p. 91.
1909. *Lachniella* Del Guercio, Redia, v. 5, p. 286.

The genus Lachnus Burmeister was erected with the following included species: *lapidarius* Fab., *fagi* Linn., *quercus* Linn., *fasciatus* Burm., and *punctatus* Burm.

Of these species the following were removed as types of other genera: *fagi*, 1857, *Phyllaphis*, and *quercus*, 1870, *Stomaphis*.

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[1] Wilson, H. F. Notes on the synonymy of the genera included in the tribe Lachnini. *In* Ann. Ent. Soc. Amer. v. 4, p. 51–54, 1911.

The following type fixations have been made for Lachnus:

1840. *Aphis roboris* Linnaeus, Westwood.
1863. *Lachnus pinicola* Kaltenbach, Passerini.
1908. *Aphis nudus* De Geer, Mordwilko.
1910. *Lachnus punctatus* Burmeister, Wilson.
1911. *Lachnus fasciatus* Burmeister, Wilson.

Now the first three fixations are invalid, since the species were not included in the original genus. The first valid fixation, therefore, is that of Wilson, 1910, when he set *punctatus* as type. This fixation, according to present rules, can not be changed in 1911 because it is an unfortunate fixation, but *punctatus* must remain the type of the genus Lachnus. The question is now purely zoological. At present *punctatus* is unknown and, therefore, the genus Lachnus must remain unknown until *punctatus* is discovered. This is the situation, if the rules are followed, and the well-known genus name will be lost to us. At the suggestion of numerous aphid workers we are holding *fasciatus* as the type of Lachnus and the Commission will be asked to suspend the rules in this case on account of the long usage of the name Lachnus.

In 1909 Del Guercio erected the genus Lachniella without setting a type but in 1911 Wilson interpreted this genus as Lachnus with *fasciatus* Burm. as type. Following this the writer definitely designated this species as type. Therefore, Lachniella will become a synonym of Lachnus.

Characters.—Eyes large, with distinct ocular tubercles present. Antennæ of six segments and with rather prominent hairs. Cornicles on somewhat shallow hairy cones. Fore wings with the radial sector short and straight; stigma elongate; media once branched. Labium lance-like.

Type (by suspension of rules), *fasciatus* Burm.

Genus DILACHNUS Baker.

Plate II, A–C.

1919. *Wilsonia* Baker, Can. Ent., v. 51, p. 212.
1919. *Dilachnus* Baker, Can. Ent., v. 51, p. 253.

Characters.—Eyes with distinct ocular tubercles. Antennæ of six segments and armed with slender hairs and circular sensoria. Cornicles on rather broad hairy cones. Fore wings with radial sector straight, media twice branched; hind wings with both media and cubitus present.

Type (fixed by Baker, 1919), *Lachniella gracilis* Wlsn.

Genus SCHIZOLACHNUS Mordwilko.

Plate II, D.

1908. *Schizolachnus* Mordwilko, Ann. Mus. Zool. l'Acad. Imp. des Sci., St. Petersbourg, v. 13, p. 375.

The genus Schizolachnus was erected by Mordwilko with *tomentosus* De Geer (*pineti* Fab.) as type.

Characters.—Eyes large and with ocular tubercles present. Antennæ of six segments and with rather prominent hairs. Cornicles on somewhat shallow hairy cones. Fore wings with the radial sector straight; stigma elongate; media once branched. Labium obtuse.

Type (fixed by Mordwilko, 1908), *Aphis tomentosus* De Geer.

Genus UNILACHNUS Wilson.

Plate II, E–G.

1919. *Unilachnus* Wilson, Ent. News, v. 30, p. 5.

The genus Unilachnus Wilson appears to be a connecting link between this subtribe and the Eulachnina. In some respects the genus is very suggestive of that subtribe. The form is elongate and the cornicles are reduced. They are armed, however, with hairs and are not so reduced as in the Eulachnina. The ocular tubercles here are very rudimentary, almost absent, and in this regard, too, the genus suggests the Eulachnina, but it seems to belong in this subtribe.

Characters.—Form elongate; cornicles somewhat reduced; ocular tubercles small; media of fore wings simple. Antennæ of six segments moderately armed.

Type, *Lachnus parvus* Wilson.

Subtribe PTEROCHLORINA.

The genera belonging in the subtribe Pterochlorina are in some ways more primitive than those of the Lachnina, but in other respects some of them are more specialized. The radial sector of the fore wings is still curved and in some genera quite elongate. This is much nearer the early type of wing than is the wing of the Lachnina where the radial sector is short and has migrated almost to the tip of the wing. Of course, the distinct curving of this vein found in some of the genera is an advance on the slightly curved elongate vein usually met with in the fossils, but to our mind the location and character of this vein are much more primitive than in the Lachnina. The stigmal area and the sexual forms appear considerably more primitive than in the Anoecina, the specialization of which has been in a different direction from that of the Lachnina. The male of Stomaphis is, however, an exception.

Characters.—Head often divided; antennæ of six segments, armed with hairs and subcircular sensoria. Fore wings with radial sector somewhat curved and not close to the tip of the wing. Cornicles on broad hairy cones. Males usually winged.

Key to the Genera of the Pterochlorina.

1. Stigma extending along costal margin almost to the tip of the wing..Longistigma.
   Stigma not so extending...2.
2. Beak extremely long, very much longer than body; antennæ covered with very fine, short hairs....................................Stomaphis.
   Beak normal in length; antennæ with rather stout hairs, often quite long...Pterochlorus.

Genus LONGISTIGMA Wilson.

Plate II, H–L.

1909. *Longistigma* Wilson, Can. Ent., v. 41, p. 385.
1909. *Davisia* Del Guercio, Redia, v. 5, p. 185.

The genus Longistigma Wilson can be distinguished at once by the shape of the stigma which is drawn out at the tip to an acute point which extends almost to the tip of the wing. The type species is very large, one of the largest aphids. Del Guercio set no type for his subgenus which was published shortly after Wilson's. Wilson placed this species as a synonym of *caryae* Harris which he made the type of Longistigma.

Characters.—Size large. Head somewhat divided. Eyes large, with distinct ocular tubercles. Antennæ of six segments, armed with subcircular sensoria and prominent hairs. Fore wings with media twice branched, radial sector not a great way from the tip of wing and stigma extending around almost to tip; hind wings with both media and cubitus present. Cornicles on broad, shallow, hairy cones. Cauda and anal plate somewhat rounded.

Oviparous female apterous. Males winged.

Type (monotypical), *Aphis caryae* Harris.

Genus PTEROCHLORUS Rondani.

Plate II, S–X.

1848. *Pterochlorus* Rondani, "Familia Hemipterorum Aphidinæ" in Nuovi Annali delle Scienze Naturali, p. 35.
1855. *Dryobius* Koch, Die Pflanzenläuse Aphiden, p. 225.
1908. *Tuberolachnus* Mordwilko, Ann. Mus. Zool. de l'Acad. Imp. des Sci. St. Petersbourg, v. 13, p. 374.
1909. *Dryaphis* Del Guercio, Redia, v. 5, p. 262.
1913. *Schizodryobius* Van der Goot, Tidj. voor Ent., v. 56, p. 130.
1917. *Pterochlorides* Archangelsky, Turkestan Ent. Stn. Rept. Tashkent.
1918. *Tuberodryobius* Das, Mem. Ind. Mus., v. 6, p. 259.

The generic name Cinaria was used for *Aphis pini* L?, and *Aphis roboris* L. with *A. pini* as type. In the writer's opinion Cinaria can not be used now with *roboris* as type. *Roboris* was used as the type of Dryobius, therefore this name is clear. Dryaphis was used with Pterochlorus as a synonym but the name as a generic name was really first used by Del Guercio in 1909. Tuberolachnus was erected in 1908 with *viminalis* Boyer as type but the difference in the abdominal tubercle is not, in the writer's opinion, sufficient for a distinction. Van der Goot's genus is plainly a synonym. The other two generic names listed were used with *Lachnus persicae* Chol. as type. This species has several abdominal dorsal tubercles but for the same reason as Tuberolachnus is held to be a synonym.

Characters.—Head somewhat rounded. Antennæ of six segments, armed with subcircular sensoria and prominent hairs. Fore wings with radial sector distinctly curved, inserted some distance from tip; media twice branched. Hind wings with both media and cubitus present. Wings often banded or mottled, cornicles on hairy cones. Cauda and anal plate rounded. Abdomen sometimes with dorsal tubercles.

Type (fixed by Rondani, 1848), *Aphis roboris* Fab. (=*roboris* L.).

Genus STOMAPHIS Walker.

Plate II, M–R.

1870. *Stomaphis* Walker, The Zoologist, v. 28, p. 2000.
1881. *Rhynchocles* Altum, Forst Zool., v. 3, p. 356.

Of the five species originally in the genus Lachnus the species *quercus* Linn. was removed by Walker as the type of his genus Stomaphis. Little confusion has arisen in regard to this species. Altum's genus was erected for *Rhynchocles longirostris*.

Characters.—Head slightly rounded; eyes large with distinct ocular tubercles. Antennæ of six segments armed with large subcircular sensoria and thickly covered with fine hairs. Cornicles situated on very broad, shallow, hairy cones. Cauda subconical, slightly rounded. Anal plate rounded. Fore wings with radial sector rather long and somewhat curved. Media twice branched; hind wings with both media and cubitus present, quite widely separated. Beak very long, much longer than body. Males wingless and with rudimentary mouth parts.

Type (fixed by Walker, 1870), *Aphis quercus* Linn.

Subtribe TRAMINA.

The subtribe Tramina is composed of insects quite specialized in nature, subterranean and often associated with ants. The typical genus Trama is the most specialized of all and is in some characters suggestive of the Fordina. Its relations with the other Lachnini, however, are shown clearly by the other genera. The genus Trama, as described by Del Guercio (Redia, v. 5) possesses small cornicles. Specimens of *troglodytes*, however, received from Schouteden, Mordwilko, and others lack cornicles entirely. Some other forms possess them either as very small cones or as large Lachnus-like structures. These latter are evidently the most primitive and to these is given the name Protrama. The insects with small cornicles are grouped under the name Neotrama. The genera may be separated as follows:

Key to the Genera of the Tramina.

1. Apterous form entirely without cornicles and with rudimentary eyes..... Trama.
   Apterous form with cornicles.. 2.
2. Apterous form with large, broad, Lachnus-like cornicles and large distinct compound eyes.. Protrama.
   Apterous form with small cone-like cornicles armed with a few hairs and more or less rudimentary eyes.................................. Neotrama.

Genus PROTRAMA, n. gen.

Plate III, P–T.

Head divided, front straight, eyes prominent and set off from the head. Antennæ of six segments armed with hairs and small subcircular protruding sensoria. Cornicles situated on broad, low, hairy cones. Cauda and anal plate rounded. Hind tarsi extremely elongate. Wing venation faint; fore wings with the media twice branched; hind wings with both media and cubitus present.

Type, *Trama radicis* Kalt.

Genus TRAMA, Heyden.

Plate III, N.

1837. *Trama* Heyden, Mus. Senkb., v. 2, p. 293.

Head divided but not prominently so, front straight. Apterous form with the eyes reduced to a few facets. Antennæ of six segments; cornicles absent; cauda subconical, rounded. Anal plate rounded. Entire insect minutely hairy.

Type (monotypical), *Trama troglodytes* Heyden.

Genus NEOTRAMA, n. gen.

Plate III, M, O.

Head somewhat flat. In the apterous form the eyes reduced; antennæ of six segments and the cornicles on very small cones with a few scattered hairs. Cauda subconical, rounded. Anal plate rounded. Entire body covered with fine hairs. Hind tarsi greatly elongate.

Type, *Trama troglodytes* Del Guercio (=*Neotrama delguercioi* Baker).

Tribe THELAXINI.

It has been the custom of most writers to place the Thelaxini (Vacuini) in the Eriosomatinae, often possibly because of the fact that only one egg is laid by the oviparous female. But the female is quite different in structure from the beakless females of the Eriosomatinae and the other forms are very different indeed.

With the Hormaphidinae there are more resemblances, the most striking of which is the structure of the thorax. The mesothorax indicates very faintly the lobes so prominent in most forms. The presence of distinct cornicles, however, is very different from the forms in the Hormaphidinae lacking these although possessing a somewhat similar thorax.

The sensory structures, too, are widely different, being similar to those found in the Phyllaphidina. Indeed, the antennæ are very like those of that subtribe. The oviparous forms of the Phyllaphidina, however, lay several eggs and may be either winged or apterous and the males, though sometimes apterous, are usually winged. The venation of the Thelaxini is more reduced than in the Phyllaphidina. Taking all of these facts into consideration it seems evident that the Thelaxini should be placed in the Aphidinae and somewhat related to the Phyllaphidina, a subtribe which belongs in the Callipterini. It is evident, however, that the Thelaxini must stand somewhat apart; it is placed, therefore, as a tribe of the subfamily Aphidinae next to the Callipterini. In this tribe the specialization of the ovipara has advanced beyond that of the Callipterini in that only one egg is laid, but according to Buckton several eggs may be laid and the distinct beak is evidence of relationship.

Characters.—Cornicles present as chitinized rings on shallow hairy cones. Antennæ somewhat setose, with oval or subcircular sensoria. Cauda somewhat semicircular or distinctly knobbed. Body usually armed with hairs or stout spines.

Sexual forms small and apterous, possessing beaks; oviparous female as a rule laying only one egg.

Forms living free upon the foliage.

The genera may be separated by the following key:

KEY TO THE GENERA OF THE THELAXINI.

Cauda distinctly knobbed .... Thelaxes.
Cauda not knobbed but somewhat semicircular .... Glyphina.

Genus GLYPHINA Koch.

Plate III, G–L

1857. *Glyphina* Koch, Die Pflanzenläuse Aphiden, p. 259.
1911. *Travaresiella* Del Guercio, Redia, v. 7, p. 299.

Characters.—Cornicles present as somewhat elevated rings. Antennæ 5-segmented, minutely setose, armed with a few stout hairs and somewhat subcircular sensoria. Fore wings with the media once branched; hind wings with only the media present. Cauda not knobbed, somewhat rounded, anal plate rounded. Body covered with hairs.

Forms living upon the foliage of plants.

Type (monotypical), *Glyphina betulae* Kalt.

Genus THELAXES Westw.

Plate III, A–F.

Vacuna of authors, not Heyden.
1840. *Thelaxes* Westw., Int. Mod. Class. Ins. Synopsis, v. 2, p. 118.

In 1837, Heyden erected his genus Vacuna based on *coccinea* Heyden. He definitely stated that he thought Phylloxera Boyer was the same genus. Kaltenbach stated that *coccinea* is a Phylloxera and so considered *dryophila* as type of Vacuna, as this species was included in the genus by Heyden. On the authority of Schouteden and other European workers *coccinea* is now considered a Phylloxera and another type, *dryophila*, can not be set for the genus in order to apply Vacuna to the genus as now understood. Vacuna with *coccinea* as type will become a synonym of Phylloxera and another name will be necessary to apply to the genus having *dryophila* as type. The next name used appears to be Thelaxes Westwood.

Characters.—Cornicles present as chitinized rings on broad low cones. Antennæ of the stem mother 5-segmented. Alate form with 3-segmented antennæ, sensoria oval or subcircular. Fore wings with the media once branched, hind wings with the cubitus lacking. Cauda distinctly knobbed, anal plate rounded. Sexual forms small and apterous, possessing distinct beaks and feeding; oviparous female producing normally but one egg.

Type (fixed by Westwood, 1840), *Thelaxes quercicola* Westw. (=*Aphis dryophila* Schr.)

Tribe CALLIPTERINI.

The tribe Callipterini is composed of forms which live upon the foliage of plants. The species in many of the subtribes have developed peculiar habits. Some forms are almost solitary whereas others live in colonies. Some have developed the power of leaping, while others are sedentary. The sexual forms do not vary greatly from the viviparous forms. In nearly all of the subtribes the males are winged, though in the Saltusaphidina they are apterous. In the other tribes intermediate males may occur in the same species with alate males. The oviparous females are nearly always apterous, although in the Phyllaphidina alate ovipara may occur. Both sexes feed and the ovaries of the oviparous female are developed so that several eggs are laid.

The wing veins are not reduced in most species. In some, however, the radial sector of the fore wings is very faint or entirely absent. This condition is met with in several genera of the Callipterina. That it is this vein which is lacking is indicated by the trachea of the freshly emerged wing. Here the media is represented by M_1, M_2, and M_{3+4}. The cubitus and first anal are distinct tracheæ, whereas the second anal is faintly indicated. In the hindwing besides the radial sector three oblique tracheæ are present; these are the media, cubitus, and first anal. Only the media and cubitus are represented in the venation.

Considerable variation is met with in the cornicles of this tribe but they are never long and prominent as in the Aphidini. The usual form is the truncate one represented in Myzocallis, Chaitophorus, etc. Very often the cornicles are sculptured. In some cases they are reduced to small cup-shaped structures and in others they are represented by mere rings.

The antennæ, as a rule, are long and slender and armed with few sensoria. These sensoria are usually small, subcircular or oval. In rare cases they are somewhat elongate.

The cauda in this tribe is as a rule knobbed and the anal plate bilobed. In some cases, however, the cauda and anal plate are both rounded. In the Saltusaphidina the anal plate is divided and the cauda remains distinctly knobbed.

Wax secretion is present to a limited extent in this tribe. It is most developed in the Phyllaphidina. Here there are large lateral abdominal wax plates in all of the forms and the insects present a wool-like appearance on the foliage. In the genus Euceraphis wax secretion is found to a limited extent. In one species, *mucidus* Fitch, it is, however, abundant and the insects of this species often seem to float in the air, a peculiar appearance common also in the Eriosomatinae. In the Saltusaphidina also distinct wax plates occur, particularly in the oviparous forms. These are arranged along the abdominal segments.

The habit of leaping is common in the Saltusaphidina as the name implies. Here the muscles of the femora are greatly enlarged for this purpose. Many of the other members of the tribe approach this condition, especially in the genus Monellia. Others, although they do not distinctly leap, drop so suddenly when disturbed that they almost appear to leap from the foliage. Our common Symydobius on the birch is difficult to collect on account of such a habit and other forms of Callipterina are very similar in action. Certain species in this tribe are closely attended by ants in return for the honeydew excreted. Some species are protected by these Hymenoptera by means of sheds or roofs built over colonies on the leaves or twigs. These sheds are found quite commonly upon the leaves of the oaks protecting the species described as *Symydobius albasiphus* by Davis and here placed as Neosymydobius.

The internal structure of insects of this tribe appears not to differ markedly from the structure in other groups. Witlaczil, however, has reported that in certain members of this tribe the intestine forms a closed loop almost similar to that found in the Chermidae.

As a rule, in this tribe, the various forms met with in the subfamily occur. In the genus Monellia, however, in some species at least, apterous viviparous forms seldom occur, nearly all the viviparous forms being alate.

The subtribes may be separated by the following key:

KEY TO THE SUBTRIBES OF THE CALLIPTERINI.

1. Eyes with ocular tubercles present, head not elongate .... 2.
   Eyes without ocular tubercles present, head often elongate .... SALTUSAPHIDINA.
2. Antennæ armed with rather long, prominent hairs .... 3.
   Antennæ usually only with minute, sometimes stout bristles .... 5.
3. Cornicles absent .... FULLAWAYINA.
   Cornicles present .... 4.
4. Cornicles cylindrical or vasiform .... PTEROCOMMINA.
   Cornicles truncate, enlarged at base .... CHAITOPHORINA.
5. Cornicles absent above .... MONAPHIDINA.
   Cornicles present, position as usual .... 6.
6. Cornicles reduced to mere rings; large lateral abdominal wax plates present .... PHYLLAPHIDINA.
   Cornicles usually not reduced to mere rings; no large abdominal wax plates present .... 7.
7. Cornicles variable, often long and somewhat swollen; oviparous female with an elongate ovipositor .... DREPANAPHIDINA.
   Cornicles never long; always short and truncate; oviparous female not always with an elongate ovipositor .... CALLIPTERINA.

Subtribe PHYLLAPHIDINA.

The subtribe Phyllaphidina is erected for the species related to the genus Phyllaphis. Many of the characters show these species as quite closely related to the Callipterina, while in other ways they very strongly suggest the Thelaxini, as indicated under the discussion of the tribe.

Characters.—Cornicles present; antennæ of six segments, minutely setose, sensoria elongate or subcircular; cauda knobbed or rounded, anal plate often bilobed, wax glands present. Forms living free or in pseudogalls. Sexual forms often alate, sometimes, however, apterous or intermediate, showing that the apterous condition has developed but recently; oviparous female producing several eggs.

KEY TO THE GENERA OF THE PHYLLAPHIDINI.

1. Anal plate deeply cleft and U-shaped .... Shivaphis.
   Anal plate entire or somewhat bilobed, not deeply cleft .... 2.
2. Cauda rounded, anal plate entire .... 3.
   Cauda knobbed, anal plate somewhat bilobed .... Phyllaphis.
3. Oviparous females with annular sensoria .... Neophyllaphis.
   Oviparous females with small transverse sensoria .... Tamalia.

Genus NEOPHYLLAPHIS Takahashi.

1920. *Neophyllaphis* Takahashi, Can. Ent., v. 52, p. 20.

Characters.—Cornicles slightly elevated. Antennæ of six segments, with narrow, transverse sensoria. Fore wings with media twice branched, hind wings with both media and cubitus present. Cauda and anal plate rounded, cauda sometimes slightly constricted. Oviparous females winged and possessing annular sensoria. Forms wax secreting and living free on the plants.

Type (monotypical), *Neophyllaphis podocarpi* Takahashi.

Genus PHYLLAPHIS Koch.

Plate IV, FF, GG.

1857. *Phyllaphis* Koch, Die Pflanzenläuse Aphiden, p. 248.

The well-known genus Phyllaphis Koch is represented by *fagi* L., but as indicated under Tamalia has been made to include species of somewhat different structure.

Characters.—Cornicles present as chitinized rings which are very slightly elevated on low conical bases. Antennæ of six segments, long and slender, minutely setose, sensoria narrowly oval. Fore wings with the media twice branched; hind wings with both media and cubitus faintly indicated. Cauda knobbed, anal plate slightly divided.

Forms living upon the foliage, sometimes producing a curling of the leaves. Males usually winged; oviparous form apterous, producing several eggs.

Type (monotypical), *Aphis fagi* L.

Genus TAMALIA n. gen.

Plate IV, HH, II.

The genus Tamalia Baker is erected for *Pemphigus coweni* Ckll., a species which has since been placed in Phyllaphis. It is, however, quite distinct from the type of the genus and undoubtedly represents a new genus. Mr. Theodore Pergande received this species, *coweni*, from California and made some notes on the material, thinking, however, that it was a new species. He gave it a provisional name and the new generic name here used. This name, as far as our knowledge goes, never was published. Among the large number of new genera conceived by Pergande this is one of the few valid ones and his manuscript name, therefore, is used here.

Characters.—Cornicles present as mere flanges on low, broad, conical bases. Antennæ of six segments minutely setose and with narrow sensoria. Fore wings with media once branched, hind wings with both media and cubitus present. Cauda and anal plate both rounded. Abdominal wax plates present.

Forms living in pseudogalls. Sexes sometimes both winged, oviparous form producing several eggs.

Type, *Pemphigus coweni* Ckll.

Genus SHIVAPHIS Das.

1918. *Shivaphis* Das, Mem. Ind. Mus., vol. 6, p. 245.

The genus Shivaphis was erected with *celti* Das as type, and *celti* is evidently the species redescribed as *Chromaphis celticolens* by Essig.[1]

[1] Essig, E. O., and Kuwana, S. I. Some Japanese Aphididæ. *In* Proc. Cal. Acad. Sci., v. 8, no. 3, p. 95, 1918.

The writer has studied a series of specimens of this species taken in 1907 on *Celtis sinensis*. There seems little doubt that the genus is related to Phyllaphis. The dorsal wax glands are of much the same structure as those found in *fagi* L. The deeply cleft anal plate, however, at once separates the two. The cauda which is almost cylindrical in some specimens is quite distinctly knobbed in others.

Characters.—Cornicles present as mere rings. Head without prominent antennal tubercles. Antennæ of six segments, sensoria elliptical. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cauda cylindrical or knobbed. Anal plate deeply divided. Males winged. Oviparous females apterous. Rows of wax glands present.

Type (monotypical), *Shivaphis celti* Das.

Subtribe CALLIPTERINA.

The subtribe Callipterina is a somewhat large and interesting one. Some of the species are very large and more or less solitary, others are small and live in colonies. In some genera apterous viviparous forms, with the exception of the stem mother, seldom occur, while in other genera they are as a rule, present. The males are in most cases alate and the oviparous forms apterous. The species of nearly all the genera live upon the leaves of plants. They do not affect these greatly, as a rule, although when abundant the insects often seriously interfere with the proper development of the trees attacked. Many of the insects are armed upon their bodies with prominent spines or tubercles.

Characters.—Cornicles present, truncate in form. Antennæ with setæ or spines, of six segments, and armed with subcircular or in a few cases somewhat elongate sensoria. Wings often clouded, mottled, or banded. Cauda as a rule knobbed, anal plate usually more or less indented or bilobed. Body often armed with capitate spines or tubercles.

KEY TO THE GENERA OF THE CALLIPTERINA.

1. Cauda distinctly knobbed, anal plate usually bilobed or sometimes deeply divided .... 3.
   Cauda not distinctly knobbed, anal plate entire or almost so .... 2.
2. Antennæ minutely setose, sensorium at base of unguis oval or somewhat rounded; oviparous female with secondary sensoria .... Symydobius.
   Antennæ not minutely setose, sensorium at base of unguis long and narrow, oviparous female without secondary sensoria .... Euceraphis.
3. Anal plate deeply divided with a U-shaped cleft so that the lobes appear as distinct; cauda knobbed .... Therioaphis.
   Anal plate bilobed, not deeply divided; cauda very markedly knobbed... 4.
4. Antennæ and often the cornicles with prominent hairs .... Callipterus.
   Cornicles and antennæ without such hairs .... 5.
5. Cornicles much reduced; wings sometimes horizontal in repose .... Monellia.
   Cornicles truncate, fairly well developed; wings not horizontal in repose... 6.

6. More or less distinct antennal tubercles present; oviparous female with secondary sensoria.. Calaphis.
No distinct antennal tubercles present; oviparous female without secondary sensoria.. 7.
7. Anal plate slightly indented, sometimes almost entire; no apterous viviparous forms developed.. Chromaphis.
Anal plate distinctly bilobed; apterous viviparous forms common.... Myzocallis.

Genus CALAPHIS Walsh.

Plate IV, S, U.

1863. *Calaphis* Walsh, Proc. Ent. Soc. Phila., v. 1, p. 301.
1913. *Siphonocallis* Del Guercio, Redia, v. 9, p. 293.
1913. *Callipterinella* Van der Goot, Tijdschr. voor Ent., v. 56, p. 118.

Walsh erected his genus *Calaphis* for his *betulella*, a species which lacks the radial sector in the wing, and on this character he based his genus. Del Guercio based his Siphonocallis on *betulaecolens* Fitch, distinguishing it from his conception of the genus Callipterus, which conception, however, was not according to type. A study of *betulaecolens* shows that in all respects, with the exception of the radial sector, this species is similar to *betulella*. Many specimens of *betulaecolens* lack the radial sector and in most cases it is only faintly indicated at best. These two species, therefore, are probably congeneric.

The genus Callipterinella was based on *betularius* Kalt., and this species proves to be very similar to *betulaecolens*. It is true that the frontal tubercles are not prominent in this species as they are in the type of Calaphis. There seems no doubt, however, that all of these three species are closely related. This relation is shown in part by the sexual forms. The oviparous females all possess sensoria on the antennæ and are very similar in other body characters. This presence of sensoria in the oviparous form, while not important in some groups, separates quite distinctly this small group of species from those of the Myzocallis type. It seems evident that the relations of *betularius* are with *betulaecolens* and *betulella*. Callipterinella, therefore, is also a synonym.

Characters.—Cornicles present, distinct, truncate. Antennæ of six segments, armed with oval sensoria and placed on more or less distinct tubercles. Fore wings with the media twice branched, the radial sector either absent or faintly indicated, sometimes, however, complete; hind wings with both media and cubitus present. Cauda distinctly knobbed, anal plate bilobed, body with prominent hairs.

Forms living more or less solitary upon the foliage, sexes not markedly different from the other forms; oviparous female producing several eggs and possessing sensoria upon the antennæ.

Type (monotypical), *Calaphis betulella* Walsh.

Genus CALLIPTERUS Koch.

Plate IV, I, J.

1855. *Callipterus* Koch, Die Pflanzenlaüse Aphiden, p. 208.
1870. *Callaphis* Walker, The Zoologist, v. 5, p. 2000.
1881. *Ptychodes* Buckton, Mon. British Aphids, v. 3, p. 39.
1904. *Panaphis* Kirkaldy, The Entomologist, v. 37, p. 279.
1917. *Nippocallis* Matsumura, Jour. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 365.

In erecting the genus Callipterus, Koch included a number of species among which was *juglandis* Kalt. In 1860, Passerini set *juglandis* as the type of Callipterus and erected his Myzocallis for species similar to *coryli* Goetz.

Most writers overlooked Passerini's work and considered the genus Callipterus in the light of Myzocallis. This is the conception commonly held by many to-day. The application of Callipterus, however, must be restricted to species essentially like *juglandis*. All the other generic names listed as synonyms were, with one exception, used with this same species *juglandis* as type and therefore require little comment.

The genus Nippocallis was erected with *kuricola* Mats. as type. Specimens of this species studied by the writer are not in good condition for the observation of the anal plate. All the characters visible, however, indicate that this species is a Callipterus.

Characters.—Cornicles present, truncate in form, rather prominent and often armed with long hairs. Antennæ of six segments, armed with stout hairs, sensoria usually oval. Fore wings with the media twice branched, hind wings with both cubitus and media present. Veins usually bordered. Radial sector often faintly indicated. Cauda not distinctly knobbed in all cases. Anal plate bilobed; body usually covered with prominent hairs.

Forms living free upon the foliage. Sexual forms not differing markedly from the other forms, oviparous female producing several eggs.

Type (fixed by Passerini, 1860), *Aphis juglandis* Frisch.

Genus CHROMAPHIS Walker.

Plate IV, O, P.

1870. *Chromaphis* Walker, The Zoologist, v. 5, p. 2001.

The genus Chromaphis was erected with *juglandicola* Kalt. as type. It is related quite closely to Monellia.

Characters.—Cornicles moderate in size, somewhat flanged. Antennæ of seven segments armed with oval sensoria. Fore wings with the media twice branched, hind wings with media and cubitus present, wings not held horizontally in repose. Cauda knobbed, anal plate slightly indented. Sexual forms somewhat similar to the viviparous ones. Males usually winged. Oviparous female with the ovaries developed normally, laying numerous eggs.[1]

Forms living free upon the foliage usually all summer; viviparous generations winged.

Type (monotypical), *Aphis juglandicola* Kalt.

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[1] Davidson believes as many as 30 may be produced by one female.

Genus THERIOAPHIS Walker.

Plate IV, K, L.

1870. *Therioaphis* Walker, The Zoologist, p. 1999.
1905. *Kallistaphis* Kirkaldy, Can. Ent., v. 37, p. 417.
1906. *Eucallipterus* Schouteden, Ann. Ent. Soc. Belg., v. 50, p. 31.[1]
1915. *Neocallipterus* Van der Goot, Beiträge zur Kennt. der Holl. Blattläuse, p. 320.

The genus Therioaphis Walker was erected with *ononidis* Kalt. as type, and *ononidis* has been shown by Theobald to be the common "yellow clover aphis," *trifolii* of Monell. This species has a deeply cleft anal plate quite different from that of Myzocallis. Eucallipterus was erected with *tiliae* L. as type, a species with quite similar structure. Eucallipterus, therefore, will become a synonym. *Betulicola* Kalt. has been used as type by Kirkaldy and Van der Goot. According to Das, Van der Goot considers this congeneric with *trifolii*. Therefore Therioaphis is the name that must be used.

Characters.—Cornicles truncate, rather constricted mesad of apex. Antennæ of six segments without prominent hairs and armed with subcircular sensoria. Fore wings with media twice branched; hind wings with both media and cubitus present. Wings often variously marked. Prothorax rather elongate; cauda knobbed. Anal plate deeply bifid so that two long, narrow lobes are formed. Body often with prominent hairs.

Type (monotypical), *Aphis ononidis* Kalt.

Genus EUCERAPHIS Walker.

Plate IV, Q, R.

1870. *Euceraphis* Walker, The Zoologist, p. 2001.
1908. *Callipteroides* Mordwilko, Ann. Mus. Zool. l'Acad. Imp. des Sci. St. Petersbourg, v. 13, p. 377.
1913. *Callipteroides* Van der Goot, Tijd. voor. Ent., v. 56, p. 151.

When Walker erected his genus Euceraphis with *betulae* L. as type he had in mind evidently the same species as that described by Koch under the same specific name, and thus separated species of this type. Mordwilko in 1900 erected the genus Callipteroides with *nigritarsus* Heyden as type. Specimens of this species received from Mordwilko show that the species he had was the *betulae* of Koch or at least a species very close to it. This would then make Callipteroides a synonym of Euceraphis. In 1913 Van der Goot used the name Callipteroides with *betulae* Koch as type and his placing, therefore, should be under Euceraphis.

Characters.—Cornicles present, truncate. Antennæ of six segments, long and slender, armed with rather narrow sensoria usually near the base of segment III, the unguis of segment VI usually not much longer than the base, sensorium at the base of unguis long, oval, and fringed; more or less distinct frontal tubercles present. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cauda usually knobbed and rather large. Anal plate usually entire. Abdomen of the alate form often with distinct wax-producing glands. Forms very large and usually solitary in habit, sexes similar to the other forms; oviparous female producing several eggs. Type (fixed by Walker, 1870), *Aphis betulae* (L.) Walker (=*Callipterus betulae* Koch).

[1] There is considerable evidence for keeping this genus distinct.

Genus MONELLIA Oestlund.

Plate IV, M, N.

1887. *Monellia* Oestlund, Geol. and Nat. Hist. Survey Minn., Bul. no. 4, p. 44.

The genus Monellia Oestlund was erected for *caryellus* Fitch and only one species was included in the genus at the time. Several other species, however, were made synonyms of *caryellus* which are quite different from that species and fall into other genera.

Characters.—Cornicles present as mere rings; antennæ slender, of six segments; sensoria oval or subcircular; head broad for its length; prothorax prominently separated from the mesothorax. Fore wings with the media twice branched; hind wings with both media and cubitus present. Wings often held flat upon the back, cauda knobbed, anal plate bilobed. Forms living solitary upon the leaves, sometimes having the power of leaping. Apterous forms rare. Sexes feeding; oviparous female laying several eggs.

Type (monotypical), *Aphis caryella* Fitch.

Genus MYZOCALLIS Pass.

Plate IV, G, H.

1860. *Myzocallis* Passerini, Gli Afidi, p. 28.
1860. *Pterocallis* Passerini, Gli Afidi, p. 28.
1894. *Subcallipterus* Mordwilko, Varshava Univ. Izviestiia, v. 8, no. 58, p. 53.
1894. *Tuberculatus* Mordwilko, Varshava Univ. Izviestiia, v. 8, no. 58, p. 60.
1913. *Callipterus* Van der Goot, Tijd. voor Ent., v. 56, p. 116.
1915. *Tuberculoides* Van der Goot, Beiträge zur Kennt. der Holl. Blattläuse, p. 313.
1917. *Acanthocallis* Matsumura, Jour. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 368.
1917. *Takecallis* Matsumura, Jour. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 373.

When Passerini erected the genus Myzocallis in 1860 he placed *coryli* Goetz as type. Later in the same work he erected his genus Pterocallis with *alni* Pass. as type. This species proves to be very similar indeed to *coryli*, so similar in most of the characters that the writer believes the genus Pterocallis to be a synonym of Myzocallis. The type of the genus, *coryli* Goetz, was also placed as the type of Callipterus by Van der Goot, in 1913, in spite of the fact that another type for that genus had been set in 1860. Callipterus Van der Goot (1913) is therefore a synonym of Myzocallis. The species *alni* Pass. is universally considered the same species as *alni* Fab., and this species was made the type of the genus Subcallipterus by Mordwilko in 1894. Subcallipterus Mordwilko, 1894, is therefore a synonym of Myzocallis for the same reason as is Pterocallis Pass., 1860. The species *querceus* Kalt. was made the type of the Tuberculatus by Mordwilko in 1894, but this species seems too closely related to *coryli*. Tuberculatus, therefore, becomes a synonym. The species *quercus* Kalt. was made the type of Tuberculoides by Van der Goot, 1915, and this is quite typically a Myzocallis. A number of genera have been erected by Matsumura which are so very little different from the type species that they are listed here as synonyms. This author follows the idea of proportions of the antennal segments as generic characters.

Characters.—Cornicles truncate without a very distinct neck; antennæ of six segments armed with a few minute bristles and oval or subcircular sensoria. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cauda knobbed; anal plate bilobed, not divided; body usually with stout hairs.

Type (fixed by Passerini, 1860), *Aphis coryli* Goetz.

Genus SYMYDOBIUS Mordwilko.

Plate IV, DD, EE.

1894. *Symydobius* Mordwilko, Varshava Universitetskiia Izviestiia, v. 8, no. 58, p. 65.
1917. *Yezocallis* Matsumura, Jour. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 369.
Symdobius of later authors.

The genus Symydobius Mord., which was erected for *oblongus* Heyden, has often been spelled Symdobius by subsequent writers. This is probably due to the erection of the genus in a Russian publication which is available to few workers, at least in this country. Specimens of this species studied were collected by Mordwilko at Petrograd and Warsaw and by Schouteden at Brussels. The species which passes under the name of *oblongus* in America is quite distinct, as has been pointed out by the writer.

Characters.—Cornicles present, truncate or with an evident neck and on a broad low base. Antennæ of six segments armed with numerous delicate hairs, sensoria somewhat oval or subcircular; sensorium at the base of the unguis not long and narrow, with a fringe but without a prominent one, cauda semicircular, anal plate similar in shape, sometimes slightly indented. Fore wings with the media twice forked; hind wings with both media and cubitus present, somewhat separated at the base.

Type (monotypical), *Aphis oblonga* Heyden.

Subtribe SALTUSAPHIDINA.

The subtribe Saltusaphidina is separated from the other related ones principally on the nature of the head. The most important character, possibly, is the structure of the eyes, in which the ocular tubercles appear to be wholly lacking.

Characters.—Forms living usually in damp places upon the foliage of sedges and grasses, narrow elongate bodies, eyes with ocular tubercles lacking, legs often modified for leaping. Oviparous forms apterous, somewhat similar to the viviparous forms, producing several eggs.

KEY TO THE GENERA OF THE SALTUSAPHIDINA.

Head considerably elongate, cornicles cup shaped, legs modified for leaping .... Saltusaphis.
Head not much elongated, cornicles mere rings, legs not modified for leaping .... Thripsaphis.

Genus THRIPSAPHIS Gillette.

Plate IV, X.

1917. *Thripsaphis* Gillette, Can. Ent., v. 49, p. 193.

The genus Thripsaphis was separated from Saltusaphis for *balli* Gillette, which the present writer had included in that genus, and certain other similar species.

Characters.—Cornicles present as slightly elevated rings; antennæ of six segments armed with subcircular sensoria. Eyes without ocular tubercles. Fore wings with the media twice branched, hind wings with the cubitus sometimes absent, cauda knobbed, anal plate divided, body with spinelike hairs.

Forms living free upon grasses and sedges in moist localities. Sexes apterous, oviparous female producing several eggs.

Type (fixed by Gillette, 1917), *Brachycolus balli* Gill.

Genus SALTUSAPHIS Theobald.

Plate IV, V, W.

1915. *Saltusaphis* Theobald, Bull. Ent. Research, v. 6, pt. 2, p. 138.

Characters.—Cornicles present, cup-shaped or truncate; antennæ of five segments, minutely setose; sensoria small and subcircular. Head elongate, ocular tubercles absent. Fore wings with the media twice branched; hind wings with the cubitus usually absent; cauda knobbed; anal plate divided, caudal extremity of the abdomen sometimes bilobed; body covered with spines which are often modified into different shapes.

Forms living more or less solitary upon the leaves of grasses or sedges in marshy regions. Sexual forms apterous, oviparous female laying several eggs.

Type (monotypical), *Saltusaphis scirpus* Theo.

Subtribe DREPANOSIPHINA.

The subtribe Drepanosiphina is evidently related to the callipterine branch of the tribe rather than the chaitophorine one. It has specialized in the opposite direction from the Monaphidina in that the cornicles are more or less prominently developed. It would appear to bear the same relation to this branch of the tribe as does the Pterocommina to the chaitophorine one. There is considerable variation in the development of the cornicles, even within certain of the genera. Some have very large cornicles, others have small ones. They all appear, however, to have the same general structure.

Characters.—Cornicles present, varying greatly in development from very small to very large. Cauda somewhat knobbed, anal plate slightly indented. Oviparous female with a long drawn out ovipositor.

KEY TO THE GENERA OF THE DREPANOSIPHINA.

1. Cornicles extremely long and somewhat swollen in the middle.....Drepanosiphum.
   Cornicles not extremely long and larger at the base........................ 2.
2. Cornicles very small, truncate...................................Neosymydobius.
   Cornicles large with a swollen region at the base..................Drepanaphis.

Genus DREPANAPHIS Del Guercio.

Plate IV, JJ–LL.

1909. *Drepanaphis* Del Guercio, Rivista di Patologia Vegetale, n. s., v. 4, no. 4, p. 49–50.
1909. *Phymatosiphum* Davis, Annals Ent. Soc. America, v. 2, p. 196.

The two generic names given were both used with the same type species, and therefore no discussion in regard to the use of the names is necessary.

Characters.—Cornicles large but not of the same shape as those of Drepanosiphum, being rather narrow toward the distal extremity and swollen at the base. Antennæ of six segments armed with subcircular or oval sensoria and a few scattered hairs. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cauda knobbed, anal plate somewhat indented. Forms living more or less solitary upon the foliage of trees. Males winged. Oviparous female with a distinct elongated ovipositor and producing several eggs.

Type (monotypical), *Drepanosiphum acerifolii* Thos.

Genus DREPANOSIPHUM Koch.

Plate IV, MM.

1855. *Drepanosiphum* Koch, Die Pflanzenlaüse Aphiden, p. 201.
1885. Type fixation, Lichtenstein, Monographie des Aphidiens, p. 175.

Cornicles very long, quite distinctly swollen in the middle or subcylindric. Antennæ of six segments with short, scattered hairs and oval or subcircular sensoria. Fore wings with the media twice branched. Hind wings with both media and cubitus present. Cauda knobbed, anal plate slightly indented.

Forms living upon the foliage of plants, males usually winged. Oviparous female with a distinct elongated ovipositor.

Type (fixed by Lichtenstein, 1885), *Aphis platanoides* Schr.

Genus NEOSYMYDOBIUS, n. gen.

The genus Neosymydobius is erected for species similar to that described as *Symydobius albasiphus* Davis. It is evident that this species is not a Symydobius. Members of that genus are very large and differ in several ways. We place the present genus here with considerable doubt.

Characters.—Cornicles small, truncate, Callipterus-like. Antennæ of six segments which are armed with a few rather stout hairs. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cauda knobbed, anal plate slightly indented. Forms living in colonies upon the foliage of trees. Body, particularly of the apterous forms, covered with rather stout spine-like hairs. Oviparous female with a long ovipositor and depositing several eggs. Males usually winged.

Type, *Symydobius albasiphus* Davis.

Subtribe MONAPHIDINA.

The subtribe Monaphidina, erected for the genus Monaphis, is very similar in most respects to the Callipterina, but lacks the cornicle dorsally. It seems evident that it is a specialization from insects of the Callipterus type in much the same way that Fullawaya is related to those of the Chaitophorus type. One genus only is known at present. This differs more from the Callipterina than does Fullawaya from the Chaitophorina.

Genus MONAPHIS Walker.

1870. *Monaphis* Walker, The Zoologist, p. 2001.
1894. *Bradyaphis* Mordwilko, Varshava Universitetskiia Izviestiia, v. 8, p. 59.

Few remarks on the synonymy of the genus Monaphis Walker are necessary as the same species was used as type in both cases mentioned. The genus is a very remarkable one, being peculiar in many ways.

Characters.—Cornicles faint; antennæ of six segments, without distinct hairs, sensoria small and circular; cauda somewhat rounded but with an acute point or projection; anal plate similar; fore wings with the media twice branched; hind wings with both media and cubitus present.

Type (fixed by Walker, 1870), *Aphis antennata* Kalt.

Subtribe CHAITOPHORINA.

The subtribe Chaitophorina is composed of aphids which are similar in many ways to the Callipterina. They differ in that they are always armed with long hairs which quite prominently cover the antennæ as well as the other parts of the body. Some of the species perhaps are given more to living in colonies than are the Callipterina, but this habit varies in that subtribe as well.

KEY TO THE GENERA OF THE CHAITOPHORINA.

1.	Cauda quite distinctly knobbed	2.
	Cauda not knobbed but rounded	3.
2.	Antennæ of five segments	Sipha.
	Antennæ of six segments	Chaitophorus.
3.	Body elongate; small dimorphic forms developed	Periphyllus.
	Body not elongate; no dimorphic forms developed	4.
4.	Antennæ of five segments	Atheroides.
	Antennæ of six segments	5
5.	Anal plate entire or slightly indented	Neothomasia.
	Anal plate divided into two quite separate parts	Patchia.

Genus ATHEROIDES Haliday.

1839. *Atheroides* Haliday, Ann. and Mag. Nat. Hist., v. 2, p. 189.

More careful collecting of marsh-inhabiting species may show that this genus is a specialization from the Chaitophorina as is the Saltusaphidina from the Callipterina, for most specimens falling here seem to lack ocular tubercles.

Characters.—Antennæ of five segments armed with stout spines. Fore wings with media twice branched; hind wings with both media and cubitus present. Cornicles reduced to mere rings. Cauda broadly rounded. Form elongate and flat. Entire insect prominently spined. Species living on sedges and grasses.

Type (set by Kirkaldy, 1906), *Atheroides serrulatus* Haliday.

Genus CHAITOPHORUS Koch.

Plate IV, CC.

1854. *Chaitophorus* Koch, Die Pflanzenläuse Aphiden, p. 1.
1870. *Tranaphis* Walker, The Zoologist, p. 1999.
1870. *Arctaphis* Walker, The Zoologist, p. 2000.
1912. *Eichochaitophorus* Essig, Pom. Coll. Journ. Ent., v. 4, p. 721.
1912. *Micrella* Essig, Pom. Coll. Journ. Ent., v. 4, p. 716.
1856. Type fixation, Gerstaecker, Bericht for 1854, p. 162.

In 1854 Koch erected the genus Chaitophorus with several species. *Aphis populi* was made the type by Gerstaecker in 1856. The same species was used by Walker as type of his genus Arctaphis and therefore this name will become a synonym. The types of both of Essig's genera show that these vary little from *populi*. The genus Tranaphis was erected with *salicivorus* Walker as type and this species is similar in general characters to *populi*. Therefore, Tranaphis will become a synonym.

In 1860 Passerini used *aceris* L. as the type of Chaitophorus and this placing has often been followed, but that of Gerstaecker has priority.

Characters.—Cornicles present, truncate, rather prominent. Antennæ of six segments, armed with subcircular sensoria and rather prominent hairs. Fore wings with the media normally twice branched, hind wings with both media and cubitus present. Cauda distinctly knobbed. Anal plate entire, sometimes somewhat indented. Sexual forms not differing markedly from the viviparous ones. Males winged, as a rule, but sometimes intermediate or apterous. Oviparous females apterous with the ovaries normally developed and producing several eggs. Both sexes feeding.

Forms living usually upon the leaves of trees; no dimorphic forms developed.

Type (fixed by Gerstaecker, 1856), *Aphis populi* L.

Genus PATCHIA, n. gen.

Characters.—Cornicles truncate; antennæ of six segments, hairy and with circular sensoria. Fore wings with the media twice branched, the radial sector absent or faintly indicated; hind wings with both media and cubitus present. Cauda rounded or slightly conical; anal plate divided into two separate parts.

Type, *Patchia virginiana* Baker.

Patchia virginiana, n. sp.

Alate viviparous female.—Antennæ as follows: III, 0.48 mm., with an even row of about 12 subcircular sensoria; IV, 0.288 mm.; V, 0.24 mm.; VI (0.16–0.192 mm.). Color brown with a large black patch on dorsum of abdomen and with lateral patches of same color. Wings with the radial sector absent and the veins heavily bordered. Apterous form almost solid velvety black. Both forms secreting wax.

Found on the bark of chestnut at East Falls Church, Va. The type is in the U. S. National Museum (Cat. No. 23063).

Genus PERIPHYLLUS Van der Hoeven.

Plate IV, AA, BB.

1852. *Phillophorus* Thornton, Proc. Ent. Soc. London, n. s., v. 2, p. 78.
1858. *Chelymorpha* Clark, The Microscope.
1863. *Periphyllus* Van der Hoeven, Tijd. voor. Ent., v. 6, p. 7.
1913. *Chaitophorinella* Van der Goot, Tijd. voor Ent., v. 56, p. 150.
1917. *Arakawana* Matsumura, Journ. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 375.

In 1852 Thornton used the name Phillophorus with his *testudinatus* as type. This name had, however, been used in 1840. Koch erected the genus Chaitophorus in 1854 and included therein a number of species. In 1856 Gerstaecker set *Aphis populi* L. as the type of Chaitophorus and therefore prevented the use of the name for species such as *testudinatus* unless all of Koch's species are included. In 1858 Clark used the name Chelymorpha with the specific name *phyllophora*. The species he discussed is the *testudinatus* of Thornton. The generic name Chelymorpha, however, was used as early as 1834 and, therefore, is not available. In 1863 Van der Hoeven employed the generic term Periphyllus with his species *testudo* as type. This name is a synonym of *testudinatus* Thornton, and the generic name seems to be the first one available.

In 1913 Van der Goot employed the generic name Chaitophorinella with *testudinatus* as type, and this name, therefore, will become a synonym of Periphyllus.

Characters.—Cornicles present, truncate in form, often sculptured. Antennæ of six segments (with the exception of the dimorph) armed with oval sensoria and prominent hairs. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cauda and anal plate rounded.

Forms living upon the foliage of trees. Sexes not strikingly different from the other forms, possessing beaks and feeding. Males winged, oviparous females with the ovaries normally developed, thus laying several eggs. Small lamellate or hairy dimorphic forms produced in summer.

Type (monotypical), *Periphyllus testudo* Van der Hoeven (=*testudinatus* Thornton).

Genus NEOTHOMASIA, n. n.

Plate IV, Y, Z.

1910. *Thomasia* Wilson, Can. Ent., v. 42, p. 386.

Wilson erected the genus Thomasia with *populicola* Thos. as type, and his description appeared in December, 1910. The same name had, however, been used for a genus of Diptera, the description of which appeared in September, 1910. A new name, Neothomasia, therefore, is necessary for Wilson's genus.

Characters.—Cornicles present; antennæ of six segments armed with subcircular sensoria and prominent hairs. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cauda and anal plate both rounded.

Forms living in colonies upon the leaves or bark of trees; no dimorphic forms produced; sexual forms not markedly different from the viviparous ones. Oviparous females laying several eggs.

Type (monotypical), *Chaitophorus populicola* Thos.

Genus SIPHA Pass.

1860. *Sipha* Passerini, Gli Afidi, p. 29.

This genus and Atheroides are distinct from the other genera in the subtribe by possessing five-segmented antennæ instead of six-segmented ones. The genus has not been much confused excepting by Thomas's placing of *rubifolii*. For a time some workers in this country were led to conceive of the genus as indicated by that species which in reality belongs in the Aphidini.

Characters.—Cornicles present, truncate, short, almost mere rings. Antennæ of five segments armed with large circular sensoria. Body form flat, entire insect covered with rather long stout hairs. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cauda knobbed, anal plate rounded. Forms living upon the leaves of grasses usually in moist localities, sometimes even submerged, the water appearing to affect them little.

Type (fixed by Passerini, 1860), *Aphis glyceriae* Kalt.

Subtribe PTEROCOMMINA.

The subtribe Pterocommina is composed of bark-feeding insects, some of which retain quite primitive characters. It is the writer's opinion, however, that they are, as a group, more specialized than the Chaitophorina, but closely related. This is indicated by the development of the cornicles met with in the species. Like the

Drepanosiphina, this development varies to a great extent in the different species.

Only two genera occur in the tribe. They may be separated as follows:

KEY TO THE GENERA OF THE PTEROCOMMINA.

Cornicles cylindrical .... Pterocomma.
Cornicles somewhat swollen .... Melanoxantherium.

Genus PTEROCOMMA Buckton.

Plate IV, PP.

1857. *Cladobius* Koch, Die Pflanzenläuse Aphiden, p. 231.
1860. *Aphioides* Passerini, Gli Afidi, p. 28.
1879. *Pterocomma* Buckton, Monog. Br. Aphides, v. 2, p. 142.
1905. *Aristaphis* Kirkaldy, Can. Ent., v. 37, p. 416.

In 1857 Koch erected the genus Cladobius with *populeus* Kalt. as type. This name, however, had been used previously. So Passerini in 1860 employed the name Aphioides. This name had also been used. Kirkaldy, therefore, gave the new name Aristaphis in 1905. In 1879, however, Buckton described the genus Pterocomma with a very similar species as type.

Characters.—Cornicles present, rather short and cylindrical. Antennæ of six segments armed with prominent hairs and subcircular sensoria. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cauda and anal plate rounded.

Type (monotypical), *Pterocomma pilosa* Buckt.

Genus MELANOXANTHERIUM Schouteden.

Plate IV, NN, OO.

1879. *Melanoxanthus* Buckton, Monog. Br. Aphides, v. 2, p. 21.
1901. *Melanoxantherium* Schouteden, Ann. Ent. Soc. Belg., v. 45, p. 113.

In 1879 Buckton described the genus Melanoxanthus with *salicis* L. as type, but, as this name was preoccupied, Schouteden suggested the name Melanoxantherium.

Characters.—Cornicles present, variable in size, but usually more or less swollen. Antennæ of six segments armed thickly with hairs and possessing oval or subcircular sensoria. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cauda and anal plate rounded.

Forms living in colonies usually on the bark of trees, males usually winged. Oviparous females laying several eggs.

Type (monotypical), *Aphis salicis* L.[1]

Subtribe FULLAWAYINA.

The subtribe Fullawayina is related somewhat closely to the Chaitophorina from which it is a specialization, as is evidenced by the reduction and total lack of the cornicles. It is very suggestive of Monaphis, but evidently arose from quite a different line of development, following Chaitophorus rather than the Callipterus group. Only one genus is represented.

[1] The writer is forced to change his view that *Pterocomma pilosa* is closely related to *populifoliae* Fitch. This was based on Pergande's published statement of his examination of the type. Later notes on the type indicated that it resembles *populea*.

Genus FULLAWAYA Essig.

1912. *Fullawaya* Essig, Pomona Coll. Journ. Ent., v. 4, p. 716.

The genus Fullawaya seems to bear somewhat the same relation to Chaitophorus that Monaphis does to Myzocallis. Were it not for the hairy condition of the antennæ and the character of the cauda and anal plate, Fullawaya might be placed as a synonym of Monaphis, but it is evidently unrelated.

Characters.—Cornicles absent; antennæ of six segments, armed with rather long bristle-like hairs, sensoria small and circular, cauda rounded and armed with long curved hairs. Fore wings with the media twice branched, hind wings with both media and cubitus present.

Forms living upon the roots of plants.

Type (monotypical), *Fullawaya saliciradicis* Essig.

Tribe GREENIDEINI.

The tribe Greenideini was first separated by Wilson under the name Trichosiphina. The insects falling here show a most remarkable development of the cornicles. These are sometimes as long as the entire body in the alate forms. In the apterous individuals they are usually swollen. In both they are very thickly covered with long hairs, a condition not met with in any of the other Aphidinae with long cornicles. It is true that some species of Macrosiphum and occasionally species of the other genera show here and there minute hairs on the cornicles, but they do not approach in any way members of this tribe in cornicle armature. The development of the cauda in this group is also remarkable.

Characters.—Cornicles present and remarkably developed into cylindrical or slightly swollen tubes often as long as the body and thickly covered with long hairs. Antennæ of five or six segments armed with oval or subcircular sensoria. Males winged. Forms living free upon the foliage.

Key to Genera of Greenideini.

1. Antennæ of five segments..Eutrichosiphum.
   Antennæ of six segments.. 2.
2. Fore wings with the media twice branched, hind wings with both media and cubitus present..Greenidea.
   Fore wings with media once branched, hind wings with neither media nor cubitus present..Greenideoida.

Genus GREENIDEA Schouteden.

Plate V, F–K.

1905. *Greenidea* Schouteden, Spol. Zeylan, v. 2, p. 181.
1906. *Trichosiphum* Pergande, Ent. News, v. 17, p. 206.

In 1905, Schouteden erected a genus for the *Siphonophora artocarpi* of Westwood and redescribed the species, giving details lacking in Westwood's paper. Pergande erected his genus Trichosiphum, making his *anonae* the type. The characters Pergande used to separate his genus were in reality those of Greenidea.

Characters.—Cornicles extremely long and hairy; antennæ of six segments armed with oval or subcircular sensoria and distinct hairs. Fore wings with media twice branched; hind wings with both media and cubitus present. Sexes winged.

Type (monotypical), *Siphonophora artocarpi* Westw.

Genus GREENIDEOIDA Van der Goot.

Plate V, L–P.

1900. *Greenidea* Wilson, not Schouteden, Ann. Ent. Soc. Amer., v. 3, p. 317.
1916. *Greenideoida* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 140.

In discussing the genera of the Trichosiphini in 1910, Wilson based his descriptions and key on specimens in the collection of the Bureau of Entomology. Material in that collection determined as *artocarpi* by Pergande proves not to be that species for it does not agree with the descriptions given either by Westwood or Schouteden. Wilson, therefore, used the two generic terms Trichosiphum and Greenidea. In reality the species listed as *artocarpi* was undescribed at that time and the species of Trichosiphum presented all of the characters of Greenidea. Since that time Van der Goot has erected the genus Greenideoida for such species as that understood by Wilson to be *artocarpi*.

Characters.—Cornicles present, very long, subcylindrical, and armed with long hairs. Antennæ of six segments armed with oval or subcircular sensoria. Fore wings with the media once branched; hind wings reduced in size and lacking both the media and cubitus. Cauda and anal plate rounded.

Type (fixed by Van der Goot, 1916), *Greenideoida elongata* V. d. Goot.

Genus EUTRICHOSIPHUM Essig & Kuwana.

Plate V, A–E.

1918. *Eutrichosiphum* Essig & Kuwana, Proc. Cal. Acad. Sci., v. 8, no. 3, p. 97.

The genus Eutrichosiphum Essig and Kuwana was erected for the species *pasaniae* Okj.

Characters.—Similar in general characters to Greenidea. Antennæ of five segments, armed with long hairs and somewhat oval sensoria. Cornicles very long, subcylindrical and covered with hairs. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cauda and anal plate rounded.

Type (monotypical), *Trichosiphum pasaniae* Okj.

Tribe SETAPHIDINI.

The correct position of the tribe Setaphidini is somewhat difficult to ascertain. In some ways it closely resembles the Aphidini, and in others suggests the Lachnini.

It has Aphis-like antennæ with, however, a reduced number of segments. The venation of the wings is also reduced. On the other hand it possesses cornicles situated on low flat cones somewhat like those of the Anoecina or Lachnina. But these cones are devoid of hairs.

It would appear that this tribe separated from the aphid line after the cornicles had lost their armature and before their development as indicated in the Aphidina and Macrosiphina began. These organs then remained somewhat primitive whereas reduction took place in the antennæ and wings. One genus only is represented.

Genus SETAPHIS Van der Goot.

Plate V, Q–X.

1916. *Setaphis* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 153.

Characters.—Cornicles present as rings, situated on low broad cones. Antennæ of five segments armed with small circular sensoria. Fore wings with the media once branched, hind wings reduced. Cauda and anal plate rounded. Body with two prominent caudal fingerlike projections.

Type (fixed by Van der Goot, 1916), *Setaphis luteus* V. d. Goot.

Tribe APHIDINI.

The tribe Aphidini is by far the largest tribe of the living Aphididae. Many of the most common species in the family as well as many of the most injurious ones belong here, and it is these forms which correspond to the popular conception of the family.

Besides being abundant they are varied, and a large number of genera is therefore found in this tribe. Specialization has taken place in a number of directions, but particularly in the development of cornicles, cauda, etc. The wings have become somewhat reduced in certain genera, but as a rule little reduction in these organs has occurred, the venation in most cases being as complete as in even the most primitive forms of the family. The antennæ have developed an elongate filamentous process to the distal segment, which in the Lachnini is represented by a very short thumblike projection. Wax secretion is found scarcely at all apart from that produced and secreted by the cornicles. The head shows certain peculiar developments in some of the tribes in that the antennæ are situated on prominent tubercles variously shaped and armed.

As a rule the body is more or less naked, being covered only by a few scattered hairs. In the peculiar specialized Cervaphidina, however, large toothed processes extend outward from the body surface.

Migration between a primary host and one or more secondary hosts often occurs. Apterous and alate viviparous forms, therefore, are common, but no definite relation exists between them. The forms feed mostly upon the leaves of trees and herbs but they may also be found feeding upon the twigs and roots. They are not infrequently attended by ants. The oviparous females are nearly always apterous, but the males, on the other hand, usually are winged. Apterous males, however, are common and intermediate forms between alate males and apterous males sometimes occur. Intermediates between apterous and alate viviparous forms are of quite common occurrence and indicate possible origin of the apterous forms. It is no doubt true, however, that in members of this tribe the equilibrium is disturbed more easily than in some of the others, and that external influences have a more sudden and noticeable effect.

We have divided the tribe into four subtribes which may be separated as follows:

KEY TO THE SUBTRIBES OF THE APHIDINI.

1. Body covered with long projections .... CERVAPHIDINA.
   Body naked with the exception of a few hairs .... 2.
2. Head without prominent antennal tubercles .... APHIDINA.
   Head with prominent antennal tubercles .... 3.
3. Wings with the radial sector normal .... MACROSIPHINA.
   Wings with the radial sector more or less united with the upper branch of the media or hind wings reduced .... PENTALONINA.

Subtribe APHIDINA.

The insects in the Aphidina show a great variation in regard to the cornicles and cauda. Some have very markedly developed cornicles, others have extremely small ones, while one genus lacks them altogether. The cauda varies from very large in genera like Hyalopterus to scarcely any visible cauda in some of the other genera. Certain of the genera appear more similar than others, for example, Hyalopterus, Pergandeidia, and Brachycolus all have small cornicles and somewhat large caudæ. Certain other genera, while appearing quite different in some ways, are evidently related. Cavariella, Hyadaphis, Aspidaphis, and Vesiculaphis all have characters which are very suggestive, although there are differences between them. So also there is a group suggesting Aphis. The various genera may be separated as follows:

KEY TO THE GENERA OF THE APHIDINA.

1. Cornicles absent .... Asiphonaphis.
   Cornicles present .... 2.
2. Cornicles swollen, not subcylindrical or tapering .... 3.
   Cornicles subcylindrical or tapering but sometimes extremely short and ringlike .... 12.
3. Fore wings with the media once branched; apterous form with very much swollen cornicles .... Vesiculaphis.
   Fore wings with the media twice branched .... 4.
4. Hind wings with the cubitus lacking .... Carolinaia.
   Hind wings with both media and cubitus present .... 5.
5. Abdomen with a dorsal projection or tubercle above cauda .... 6.
   Abdomen without this structure .... 7.

6. Tubercle very large, entirely covering posterior part of body; cornicles small, opening at the side.................................... Aspidaphis.
Tubercle of moderate size, as large as cauda in the apterous form; cornicles normal, opening at the end.................................... Cavariella.
7. Cornicles long, very abruptly and distinctly swollen..............Liosomaphis.
Cornicles of varying lengths, gradually swollen.......................... 8.
8. Cauda short and abruptly conical; cornicles about the same length as cauda and swollen in the middle..........................Brevicoryne.
Cauda not strikingly short or abruptly conical........................ 9.
9. Cornicles as short as the width of cauda at base or shorter............... 10.
Cornicles as long as or longer than the cauda.......................... 11.
10. Cornicles minute, tubercle-like.................................Brachycolus.
Cornicles considerably longer than their diameter; cauda, particularly in the apterous form, large and long..........................Hyalopterus.
11. Cauda in the apterous form long and broad, as long as the cornicles..Hyadaphis.
Cauda shorter than the cornicles, not correspondingly long and broad..Rhopalosiphum.
12. Tarsi atrophied... 13.
Tarsi normal.. 14.
13. Antennæ of six segments; cornicles rather short........................Atarsos.
Antennæ of five segments; cornicles very long and slender..........Mastopoda.
14. Cauda apparently absent, or a mere rounded platelike structure.......... 21.
Cauda normal in appearance but often very short....................... 15.
15. Fore wings with media once branched................................. 22.
Fore wings with media twice branched................................. 16.
16. Antennæ of five segments.. 24.
Antennæ of six segments... 17.
17. Cornicles small, as short as width of cauda at base, which is without constriction.. 18.
Cornicles usually as long as or longer than cauda, Aphis-like............ 19.
18. Cauda very long and large in the apterous form ....Pergandeidia.
Cauda extremely short and subconical............................Microsiphum.
19. Cauda short and abruptly conical....................................Anuraphis.
Cauda elongate and constricted near base............................ 20.
20. Hind wings with media and cubitus present ....Aphis.
Hind wings with only one oblique vein.........................Hysteroneura.
21. Cornicles minute, not as long as wide..........................Cryptosiphum.
Cornicles moderate in length.......................................Acaudus.
22. Antennæ of six segments...Toxoptera.
Antennæ of five segments.. 23.
23. Apterous form with a prominent median projection on the vertex and with four-segmented antennæ; cornicles minute..................Sanbornia.
Apterous form normal..Yamataphis.
24. Cornicles elongate, Aphis-like ....Cerosipha.
Cornicles extremely short, body of apterous form, much arched.Siphonatrophia.

Genus ACAUDUS V. d. Goot.

Plate VI, A, B.

1913. *Acaudus* Van der Goot, Tijd. voor Ent., v. 56, p. 97.
1917. *Macchiatiella* Del Guercio, Redia, v. 12, p. 210.
1917. *Hannabura* Matsumura, Journ. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 377.

Van der Goot erected his genus Acaudus with *lychnidis* L. as type. This species is quite similar to an Aphis without a cauda or with a very short, somewhat rounded cauda. The cornicles are not long.

Del Guercio's genus had his *trifolii* placed as type. The cornicles of this species appear to be a little longer than those of the type of Van der Goot's genus, but in other respects the insects seem to be quite similar. We feel that they belong to the same genus. We are keeping this genus distinct from Cryptosiphum, not only because of the minute cornicles in that genus but also on account of the peculiar head structure which is there seen. It is not typically Aphis-like.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cornicles cylindrical, of moderate length; cauda reduced to a broad, short, rounded structure.

Type (fixed by Van der Goot, 1913), *Aphis lychnidis* L.

Genus ANURAPHIS Del Guercio.

Plate VI, C–F.

1907. *Anuraphis* Del Guercio, Redia, v. 4, p. 190.
1913. *Brachycaudus* Van der Goot, Tijd. voor Ent., v. 56, p. 97.
1913. *Dentatus* Van der Goot, Tijd. voor Ent., v. 56, p. 98.
1913. *Semiaphis* Van der Goot, Tijd. voor Ent., v. 56, p. 105.
1917. *Yezabura* Matsumura, Journ. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 392.
1918. *Sappaphis* Matsumura, Trans. Sapporo Nat. Hist. Soc., v. 7, pt. 1, p. 18.

In 1907 Del Guercio erected the genus Anuraphis in which were included *pyri* Koch, *lappae* Koch, *iridis* Del Guercio, *ranunculi* Kalt., *myosotidis* Koch, *centaureae* Koch, *prunicola* Kalt., *tragopogonis* Kalt., *iani* Feer, *farfarae* Koch, and *persicae* Boyer.

These species, with the exception of *lappae* and *tragopogonis* which seem to belong to Aphis, have a broadly and somewhat abruptly conical cauda quite unlike that of the genus Aphis. In 1913, Van der Goot erected his genus Brachycaudus with one of these species, *myosotidis*, as type without referring any of the species to Anuraphis at all. It is evident that Brachycaudus is a synonym of Anuraphis. At the same time he erected the genus Semiaphis with *carotae* Koch as type. A study of this species, as seen in Plate VI, makes it evident that this is a species of the same general type. Semiaphis thus becomes a synonym of Anuraphis. Based on the minute tubercles, particularly on the head and caudal portion of the abdomen, Van der Goot also erected the genus Dentatus with *sorbi* Kalt. as type. Apart from these tubercles *sorbi* is in the character of the cauda, etc., a typical Anuraphis. In our American rosy aphis, a species very similar to *sorbi*, these tubercles are absent in many individuals, and in the fall migrants the caudal ones are nearly always absent. If this character were retained, therefore, the species would belong in one genus as far as the spring migrant is concerned, and in another genus when the fall migrant is considered. Dentatus, therefore, becomes also a synonym of Anuraphis.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments and armed with subcircular sensoria. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cornicles cylindrical, often short, though sometimes moderately long; cauda short, broad, and abruptly conical, never elongate and constricted as in Aphis. Males usually winged. Oviparous forms apterous.

Type (fixed by Del Guercio, 1907), *Aphis pyri* Koch.

Genus APHIS L.

Plate VI, G–I.

1758. *Aphis* Linnaeus, Systema Naturae, 10th ed., p. 451.
1817. *Loxerates* Rafinesque, Am. Mo. Mag. & Crit. Review, v. 1, p. 361.
1907. *Uraphis* Del Guercio, Redia, v. 4, p. 192.
1907. *Microsiphon* Del Guercio, Redia, v. 4, p. 192.
1913. *Myzaphis* Van der Goot, Tijd. voor Ent., v. 56, p. 96.
1913. *Stenaphis* Del Guercio, Redia, v. 9, p. 185.
1916. *Longiunguis* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 112.
1916. *Melanaphis* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 61.
1917. *Abura* Matsumura, Jour. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 407.
1917. *Arimakia* Matsumura, Jour. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 405.

A number of species were included in the original genus by Linnaeus. Of these Lamarck set *Aphis ulmi* L. as type in 1801, and in 1802 Latreille set *Aphis sambuci* L. as type. *Aphis ulmi* L. is, according to Passerini, *Eriosoma lanuginosa* Hartig and the species now placed in Tetraneura. *Sambuci* is retained here as type and a request will be submitted that this species be fixed definitely by the International Commission. It would greatly disarrange the economic literature to change the meaning of this common name.

In 1907 Del Guercio erected two genera, Uraphis and Microsiphon based on the relative length of the cornicles and cauda. When considering certain individual species this would appear as a very fair character for use. But when large series of species are studied it will be found that in the species having the cauda of the typical Aphis shape there are all gradations of cornicles from the very short to the very long. This will be seen also in the forms having the abruptly conical cauda. Some species have very short cornicles and some quite long ones. Moreover, in the same species the cornicles in the different forms will bear a different relation to the length of the cauda. Species, therefore, having cornicles and cauda of essentially the same character should not be used as types of different genera depending on the length of the cornicles. If this were the case, certain species which are close to the border line of separation would on some individuals fall in one genus and on other individuals fall in a different genus. Under this rule, *sacchari* Zehnt. would, it is believed, belong to the genus Aphis, and Longiunguis, therefore, be a synonym of Aphis. Likewise the genus Melanaphis would be a synonym of Aphis. This genus was erected with *bambusae* Kirk. as type. The cornicles are short but the cauda is aphis-like. Where the generic characters are considered, the genus appears a synonym.

The genus Myzoaphis was erected by Van der Goot with *Aphis rosarum* Kalt. and *Aphis abietina* Walker. These two species show practically no antennal tubercles and are very little different from a typical Aphis, excepting in the clothing of the antennæ and body. The cauda as figured by Van der Goot is quite conical, but the writer's specimens are somewhat different from this and specimens of *abietinus* do not show a cauda exactly like his figure. In fact, they appear more like an Aphis. This genus, therefore, should not be separated or it will necessitate the separation of very many other forms under new names.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments and armed with subcircular sensoria. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cornicles cylindrical or slightly tapering. Cauda usually not as long as the cornicles, subconical, rather elongate, constricted about the middle. Anal plate rounded. Males usually winged, oviparous females apterous.

Type (by suspension of rules), *Aphis sambuci* L.

Genus ASPIDAPHIS Gillette.

Plate VI, L–O.

1917. *Aspidaphis* Gillette, Can. Ent., v. 49, p. 196.

The genus Aspidaphis appears to be related both to Cavariella and to Vesiculaphis. It has the short, blocky form of Vesiculaphis and also the peculiar integument. On the other hand, certain species with a similar integument are met with in Cavariella. The development of the dorsal abdominal tubercle is here very pronounced and the cornicles have taken on a peculiar shape.

Characters.—Head without prominent antennal tubercles; antennæ short, of five segments, armed with subcircular sensoria. Wing venation normal. Cornicles very small, somewhat swollen near the distal extremity and with the opening in the side of the cornicle, not at the tip. Abdomen with a dorsal caudal tubercle developed into a large conical process extending beyond and fully covering the cauda in the apterous form. Body elongate.

Type (monotypical), *Aspidaphis polygonii* Gill.

Genus ASIPHONAPHIS Wilson & Davis.

1919. *Asiphonaphis* Wilson & Davis, Ent. News, v. 30, p. 39.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments armed with subcircular sensoria. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cornicles absent entirely. Abdomen with large lateral tubercles. Cauda somewhat conical or Aphis-like. Anal plate rounded.

Type (monotypical), *Asiphonaphis pruni* Wilson & Davis.

Genus ATARSOS Gillette.

Plate VI, P–S.

1911. *Atarsos* Gillette, Ent. News, v. 22, p. 440.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments armed with subcircular, somewhat tuberculate sensoria; fore wings with the media twice branched, hind wings with both media and cubitus present. Cornicles rather short, subcylindrical; cauda somewhat conical, not quite as long as the cornicles; anal plate rounded. Tarsi atrophied in all the forms.

Type (monotypical), *Atarsos grindeliae* Gill.

Genus BRACHYCOLUS Buckton.

Plate VI, T, U.

1879. *Brachycolus* Buckton, Mon. British Aphides, v. 2, p. 146.
1913. *Brachysiphum* Van der Goot, Tijd. voor Ent., v. 56, p. 105.

The genus Brachycolus was erected with *stellariae* Hardy as type and is easily recognized from the structure of the cornicles. Van der Goot's genus is in all essential respects the same, the type of that genus being *thalictri* Koch.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments and armed with subcircular sensoria. Wing venation normal. Cornicles very small, especially in the apterous form. Cauda medium in size and conical. Body elongate; legs and antennæ usually short.

Type (monotypical), *Aphis stellariae* Hardy.

Genus BREVICORYNE V. d. Goot.

Plate VI, J, K.

1915. *Brevicoryne* Van der Goot, Beiträge z. Kennt. d. Holl. Blattläuse, p. 245.
1916. *Oedisiphum* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 122.
1918. *Brevicoryne* Das, Mem. Ind. Mus., v. 6, p. 179.

The genus Brevicoryne was erected with *Aphis brassicae* L. as type, a species in which the cornicles are very short and somewhat swollen in the middle, and the cauda conical. In the species *Oedisiphum compositarum* V. d. Goot quite similar characters are found. The cornicles appear to be somewhat more slender but in the main the species appear alike. Oedisiphum, therefore, becomes a synonym.

Characters.—Head without prominent antennal tubercles; antennæ of six segments and armed with subcircular sensoria. Wing venation normal. Cornicles short, not much longer than the cauda and swollen in the middle. Cauda short and broadly conical.

Forms not especially elongate.

Type (monotypical), *Aphis brassicae* L.

Genus CAROLINAIA Wilson.

Plate VI, V, W.

1911. *Carolinaia* Wilson, Can. Ent., v. 43, p. 61.

The genus Carolinaia Wilson is related very closely to Rhopalosiphum. In fact some of the species placed here are distinguished from members of that genus only by the fact that the cubitus is lacking in the hind wing. It is true that the type species was described as having five-segmented antennæ in the apterous form. But other species, like this in all other respects, have normal six-segmented antennæ. Certain species of Rhopalosiphum will show strains in which nearly all of the individuals will have five-segmented antennæ and yet the normal antenna for such species is a six-segmented one. In this closely related genus, therefore, it is not surprising if a similar condition is met with.

Characters.—Head without prominent antennal tubercles. Antennæ of five or six segments armed with subcircular sensoria. Venation of the fore wings normal; hind wings with the cubitus absent; cornicles elongate, slightly swollen near the distal extremity, but without a prominent neck near the proximal end. Cauda rather broadly conical.

Type (monotypical), *Carolinaia caricis* Wlsn.

Genus CAVARIELLA Del Guercio.

Plate VI, X–Z.

1911. *Cavariella* Del Guercio, Redia, v. 7, p. 323.
1914. *Corynosiphon* Mordwilko, Faune de la Russie-Insecta, Aphidodea, p. 73.
1917. *Nipposiphum* Matsumura, Journ. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 410.

Two new genera were erected in recent years: One by Del Guercio, Cavariella, with *pastinacae* L. as type; the other by Mordwilko, called Corynosiphon, but with no species definitely given. In a footnote, however, Mordwilko refers *capreae* Fab. to his Corynosiphon. Both of these genera, therefore, were used for insects of the same general type. This may be said too of Nipposiphum.

Characters.—Head without distinct antennal tubercles; antennæ of six segments, armed with prominent sensoria. Wing venation normal. Cornicles somewhat swollen near the distal end; cauda rather elongate, somewhat conical; abdomen with a tubercle or horn above the cauda, this tubercle or horn most prominent in the apterous form. Males winged; oviparous females usually apterous.

Type, *Aphis pastinacae* L. [1]

Genus CEROSIPHA Del Guercio.

1900. *Cerosipha* Del Guercio, Nuove Rel. Staz. Firenze, ser. 1, no. 2, p. 116.
1918. *Metaphis* Matsumura, Trans. Sapporo Nat. Hist. Soc., v. 7, pt. 1, p. 1.

The genus Cerosipha Del Guercio was erected for a species, *passeriniana* Del Guercio, somewhat similar to Aphis but with five segments to the antennæ. The writer has been unable to study the type species and has based his remarks on *rubifolii* Thomas, an American species.

Characters.—Head without prominent antennal tubercles; antennæ of five segments, Aphis-like, armed with subcircular sensoria. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cornicles cylindrical or somewhat tapering, cauda Aphis-like, somewhat tapering.

Type (monotypical), *Cerosipha passeriniana* Del G.

Genus CRYPTOSIPHUM Buckton.

Plate VI, PP, QQ.

1879. *Cryptosiphum* Buckton, Mon. Br. Aphides, v. 2, p. 144.

The genus Cryptosiphum Buckton can be distinguished from others having very short cornicles by the cauda which is here short and rounded, while in most other cases it is very long.

Characters.—Head without distinct antennal tubercles. Antennæ of six segments, rather short, and with subcircular sensoria. Fore wings with the media either once or twice branched. Hind wings with both media and cubitus present. Cornicles sub-

[1] The writer has a record to the effect that in a published paper Del Guercio used *pastinacae* as type of Cavariella, but he has been unable to locate the publication and can not reach Doctor Del Guercio through the mails.

cylindrical but extremely short, not as long as wide. Cauda very short and rounded, not Aphis-like; anal plate rounded.

Type (monotypical), *Cryptosiphum artemisiae* Buckt.

Genus HYSTERONEURA Davis.

1919. *Heteroneura* Davis, Can. Ent., v. 51, p. 228.
1919. *Hysteroneura* Davis, Can. Ent., v. 51, p. 263.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments armed with subcircular sensoria. Fore wings with the media twice branched. Hind wings with the cubitus absent. Cornicles somewhat tapering or subcylindric, cauda Aphis-like; anal plate rounded.

Type (monotypical), *Aphis setariae* Thos.

Genus HYADAPHIS Kirk.

Plate VI, AA, BB.

1904. *Hyadaphis* Kirkaldy, The Entomologist, v. 37, p. 279.
1863. *Siphocoryne* Passerini, Aphididæ Italicæ, p. 8 (not Siphocoryne, 1860).

As indicated under the discussion of Siphocoryne, Passerini set *xylostei* as type of his genus in 1863. *Nymphaeae* had, however, been set in 1860, so Kirkaldy gave Hyadaphis to Passerini's 1863 conception, of which genus *xylostei* becomes the type. *Xylostei* has no caudal horn and is quite similar in general appearance to a Rhopalosiphum. We may separate the two genera, however, on the cauda, which in *xylostei*, particularly in the apterous form, is very large, fully as long as the cornicles, and broad, quite unlike that of *nymphaeae*. Several other species which have generally been considered in the same genus with *xylostei* possess a distinct caudal projection on the abdomen. One of these has been made the type of Cavariella so that such species will be removed from our conception of Hyadaphis.

Characters.—Head without prominent antennal tubercles; antennæ of six segments which are rather abundantly armed with tuberculate sensoria. Wing venation normal. Cornicles somewhat swollen but not prominently so. Cauda, particularly in the apterous form, large, as long as the cornicles, and broad. Males usually winged; oviparous females apterous; summer forms usually feeding on the Umbelliferæ.

Type (fixed by Kirkaldy, 1904), *Aphis xylostei* Schrk.

Genus HYALOPTERUS Koch.

Plate VI, RR-WW.

1854. *Hyalopterus* Koch, Die Pflanz. Aphiden, p. 16.
1917. *Hayhurstia* Del Guercio, Redia, v. 12, p. 208.

Aphis pruni Fab. was set as the type of this genus in 1860 by Passerini. In 1917 Del Guercio erected the genus Hayhurstia. There is little difference between the two as will be seen by examining the drawings given herewith. The cauda in Hayhurstia is slightly narrower than that in Hyalopterus. It is the writer's opinion that the two represent only one genus.

Two other genera may be mentioned here. They are Brachycolus Buckt. and Pergandeidia Schout. Specimens of the type species of Brachycolus show that this genus is quite similar to Hyalopterus, but it differs in the cornicles. In Brachycolus the cornicles are very small, almost mere rounded swellings in the apterous form, whereas in Hyalopterus the cornicles are in the apterous form of fair size and not distinctly swollen.

Specimens of the type of Pergandeidia received from Schouteden show that this genus is very close to Hyalopterus and is probably almost too close for a very distinct genus. The diagnosis given by Wilson (1910) for this genus does not agree with the type species as determined by the author of the genus.

In the specimens examined by the writer the cauda, as will be seen in the drawings, is very much longer than the cornicles, bearing about the same ratio as seen in Hyalopterus.

Characters.—Head without distinct antennal tubercles, antennæ of six segments armed with subcircular sensoria. Wing venation normal. Cornicles very short, not much longer than the cauda is wide at its base, swollen beyond the middle, particularly in the alate form. Cauda long and broad, considerably longer than the cornicles. Form of the insects elongate, often more or less flat.

Type (fixed by Passerini, 1860), *Aphis pruni* Fab. (=*A. arundinis* Fab.).

Genus LIOSOMAPHIS Walker.

Plate VI, NN, OO.

1868. *Liosomaphis* Walker, The Zoologist, p. 1119.

The genus Liosomaphis Walker is related somewhat closely to Rhopalosiphum. The two genera, however, can be separated on the structure of the cornicles.

In Liosomaphis the cornicles have a very distinct neck near the proximal extremity, due to a constriction behind the prominent swelling. This is strikingly evident in the apterous form, as well as in the alate one. In Rhopalosiphum, on the other hand, there is no abrupt swelling, but only a gradual one which is not at all prominent, as in Liosomaphis.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments armed with subcircular sensoria. Wing venation normal. Cornicles elongate, distinctly swollen in the middle, and with a constricted neck near the base. Structure in both the apterous and alate forms similar. Cauda not as long as the cornicles, somewhat narrowly conical. Males usually winged; oviparous females usually apterous.

Type (monotypical), *Aphis berberidis* Kalt.

Genus MASTOPODA Oestlund.

1886. *Mastopoda* Oestlund, Minn. Geol. Surv. Rept. 14, p. 52.

The genus Mastopoda Oestlund, like Gillette's Atarsos, is peculiar in that the tarsi are atrophied.

Characters.—Head without distinct antennal tubercles. Antennæ of five segments. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cornicles somewhat long and cylindrical. Cauda short, conical, Aphis-like. Legs with the tarsi absent and provided instead with a membranous disk which enables the insect to walk inverted on smooth surfaces.

Type (monotypical), *Mastopoda pteridis* Oestlund.

Genus MICROSIPHUM Cholodkovsky.

1908. *Microsiphum* Cholodkovsky, Zool. Anz., v. 32, p. 687.

Characters.—Head without prominent antennal tubercles, although with apparent ones. Antennæ of six segments, rather long and slender. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cornicles very short, not much longer than wide and often scarcely visible in the alate form. Cauda extremely short and subconical or slightly rounded; anal plate rounded.

Type (monotypical), *Microsiphum ptarmicae* Chol.

Genus PERGANDEIDIA Schouteden.

Plate VI, KK-MM.

1903. *Pergandeidia* Schouteden, Zool. Anz., v. 26, p. 685.
1913. *Longicaudus* Van der Goot, Tijd. voor Ent., v. 56, p. 146.
1915. *Rhizoberlesia* Del Guercio, Redia, v. 10, p. 246.
1918. *Yezosiphum* Matsumura, Trans. Sapporo Nat. Hist. Soc., v. 7, pt. 1, p. 7.
1918. *Brachyunguis* Das, Mem. Ind. Mus., v. 6, p. 227.

The genus Pergandeidia was erected by Schouteden with his *ononidis* as type. The characterization of the genus in this paper is based on specimens of the species received from Schouteden, and though it does not agree with the characterization of the genus as sometimes given, it seems necessary to follow the type species in forming a conception of the genus. In 1913 Van der Goot erected the genus Longicaudus and placed *trirhodus* Walker as type. In studying this species differences sufficient for good generic distinction have not been found, and, therefore, the conclusion may be drawn that Longicaudus is a synonym of Pergandeidia. Del Guercio's genus is placed here also, although a study of the type species, which is not available, possibly may show the cauda to be somewhat different.

Characters.—Head with no prominent antennal tubercles; antennæ of six segments. Fore wings with media twice branched, hind wings with both media and cubitus present. Cornicles very short, almost as wide as long. Cauda very long and broad.

Type (monotypical), *Pergandeidia ononidis* Schout.

Genus RHOPALOSIPHUM Koch.

Plate VI, FF-JJ.

1854. *Rhopalosiphum* Koch, Die Pflanz. Aphiden, p. 23.
1860. *Siphocoryne* Passerini, Gli Afidi, p. 28.
1882. *Rhopalosiphon* Scudder, Nomenclator Zoologicus.
1910. *Coloradoa* Wilson, Ann. Ent. Soc. Am., v. 3, p. 323.
1915. *Siphonaphis* Van der Goot, Beiträge zur Kennt. d. Holl. Blattläuse, p. 238.
1918. *Stephensonia* Das, Mem. Ind. Mus., v. 6, p. 175.
1856. (Type fixation) Gerstaecker, Bericht for 1854, p. 162.

There has been much confusion in regard to this genus. Koch included a number of diverse species. In 1856 Gerstaecker definitely set *Aphis nympheae* L. as type. Overlooking this, Passerini in 1860 set *persicae* Sulz. as type. In 1863, however, he changed this name to *dianthi* Schrank. In 1860 Passerini erected the genus Siphocoryne with *A. nympheae* L. as type. Having the same type this must, therefore, become a synonym of Rhopalosiphum. In 1863 Passerini placed *nympheae* in Rhopalosiphum, although he set *dianthi* as type, and he used Siphocoryne in a different sense with *xylostei* Schrank as type. Such a procedure is inadmissible, and Kirkaldy therefore renamed this genus Hyadaphis.

The genus Coloradoa Wilson was erected with *rufomaculata* Wilson as type. Although much smaller, this species is essentially like *nympheae* in structure, and we therefore consider the genus a synonym of Rhopalosiphum.

The genus Siphonaphis Van der Goot was erected with *nympheae* L. as type. Having the same type, therefore, it must become a synonym of Rhopalosiphum. *Lahorensis* Das is quite similar.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments with the usual subcircular sensoria present. Wing venation normal. Cornicles moderately long and slender, slightly swollen near their distal extremities. Cauda rather elongate, not as long as the cornicles, and not broad. Abdomen without a caudal horn or projection above the cauda. Males usually winged; oviparous females usually apterous.

Type (fixed by Gerstaecker, 1856), *Aphis nympheae* L.

Genus SANBORNIA, n. gen.

Plate VII, F–L.

The genus Sanbornia is erected for a peculiar form living on juniper at College Station, Tex., and forwarded to the Bureau by Charles Sanborn. This species was determined as undescribed by Mr. Pergande who had planned to publish on it. He had given it the name *juniperi*. The type is in the U. S. National Museum (Cat. No. 23064).

Characters.—Head without prominent antennal tubercles. Antennæ of five segments, armed with circular sensoria. Fore wings with the media once branched, hind wings with only the media present, cornicles minute; cauda elongate. Apterous form with four-segmented antennæ and with a prominent mushroom-like projection on the vertex.

Type, *Sanbornia juniperi* Perg.

Sanbornia juniperi Pergande, n. sp.

(Description by Mr. T. Pergande.)

Apterous form.—The head is most remarkable in front, having a large, squarish, bilobed projection about the middle and each side of it; close to the insertion of the antennæ is a prominent, short, and conical protuberance. There is also at the inner side of the first antennal joint a long and slightly conical protuberance. The antennæ are but four-jointed, the spur shorter than the basal section of the joint. Nectaries are not visible (?); the tail is rather long and uniformly elongate conical; the tarsi are very short, the first joint appears to be minute, and in alcoholic specimens seems to be withdrawn into the tibiæ; the last abdominal segment is semicircular.

Genus SIPHONATROPHIA Swain.

Plate VII, A–E.

1918. *Siphonatrophia* Swain, Ent. News, v. 29, p. 363.

Characters.—Head without prominent antennal tubercles. Antennæ of five segments and armed with circular sensoria. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cauda elongate and conical. Cornicles extremely short. Body of apterous form considerably arched.

Type (monotypical), *Cerosipha cupressi* Swain.

Genus YAMATAPHIS Matsumura.

1917. *Yamataphis* Matsumura, Jour. Coll. Agr. Tohoku Univ., v. 7, pt. 6, p. 412.

Characters.—Head without prominent antennal tubercles. Antennæ of five segments armed with small circular sensoria. Fore wings with the media once branched; hind wings with both media and cubitus present. Cornicles subcylindrical. Cauda somewhat conical.

Type (fixed by Matsumura, 1917), *Yamataphis oryzae* Mats.

Genus TOXOPTERA Koch.

Plate VI, DD, EE.

1857. *Toxoptera* Koch, Die Pflanz. Aphiden, p. 253.
1891. *Ceylonia* Buckton, Ind. Mus. Notes, v. 2, p. 35.

Koch's genus was erected for his *aurantiae*, a well-known species on citrus, etc. Buckton erected his genus for a species he described as *theaecola*. Specimens of *aurantiae* from various regions and specimens of *theaecola* from Zehntner substantiate the placing of *theaecola* as a synonym of *aurantiae*. Ceylonia will then become a synonym of Toxoptera. Even if the two species were held to be distinct, this would necessarily be the case.

Characters.—Head without prominent antennal tubercles. Antennæ of six segments, armed with subcircular sensoria. Fore wings with the media once branched, hind wings with both media and cubitus present. Cornicles moderate in length, subcylindric, tapering. Cauda of moderate length, somewhat constricted near the base.

Type (monotypical), *Toxoptera aurantiae* Koch (*aurantiae* Boyer).

Genus VESICULAPHIS Del Guercio.

Plate VII, M–Q.

1911. *Vesiculaphis* Del Guercio, Redia, v. 7, p. 464.

Characters.—Apterous form elongate; antennæ short, composed of five segments and situated on the under side of the head. Top of head forming a ledge which extends out over the antennæ forming an angle in front of the eye; eyes protruding. Cornicles large, very much swollen and curved, opening minute and flanged; cauda somewhat conical, rounded at the tip. Anal plate rounded; posterior part of abdomen extending out over the anal plate and somewhat over the cauda. Alate form with six-segmented antennæ armed with subcircular tuberculate sensoria. Fore wings with the media once branched, hind wings with both media and cubitus present. Cornicles somewhat slender, swollen, and slightly constricted at the tip. Cauda conical, not as long as the cornicles, anal plate rounded.

Type (monotypical), *Toxoptera caricis* Fullaway.

This genus is one of those peculiar genera, like Aspidaphis Gillette, which seem to be related to Rhopalosiphum.

Subtribe CERVAPHIDINA.

The subtribe Cervaphidina is a most interesting and peculiar one. The specialization is remarkable in that long processes are developed on the body and considerable reduction has taken place in the wings and antennæ while no Aphis-like cauda is found. Only two genera are known, which may be separated as follows:

KEY TO THE GENERA OF THE CERVAPHIDINA.

Cornicles swollen; body spine-like projections not armed with teeth...Anomalaphis.
Cornicles not swollen; body spine-like projections armed with teeth.....Cervaphis.

Genus ANOMALAPHIS, n. gen.

Plate VIII, D-F.

Characters.—Body armed with elongate tubercle-like projections, particularly on the caudal portion; antennæ five-segmented in both apterous and alate forms, armed with subcircular sensoria. Fore wings with the media once branched; hind wings considerably reduced, with the cubitus absent. Cornicles distinctly swollen; cauda and anal plate reduced.

Type *Anomalaphis comperei* Pergande.

Anomalaphis comperei Pergande, n. sp.

Among the many descriptive notes left by Mr. Theo. Pergande are some recording a peculiar species from Australia. This proves to represent an undescribed genus in the Cervaphidina. Pergande recognized the species as typical of a new genus to which he gave the manuscript name here used. He left no description of the genus and his notes on the species are given here exactly as he left them. The type is in the United States National Museum collection of Aphididae (Cat. No. 23065).

Feb. 18, 1907, Rec. from Compere, a lot of Aphides, found in 1901, on *Acacia* and *Eucalyptus*, along the beach at Albany, West Australia, which represents a new genus among Rhopalosiphins, and is a most remarkable Aphid in various respects. The antennæ, in the apterous and migratory female, are but 5-jted. while the spur is rather short and resembles that of *Chaitophorus*. The front wings are ample and reach considerably beyond the end of the body, with the third discoidal having but one fork, as in *Schizoneura*. The hind wings are very short and narrow and reach out to the apex of the 1st vein of the anterior wings, there is also but 1 discoidal, straight, and near the apex of the wing. The nectaries are short, clavate, and similar to those of *Siphocoryne*, the tail appears to be wanting. The abdomen of the migrant appears to have been of a dusky yellowish green, with transverse rows of small, black spots or tubercles, and blackish sutures between the segments. The eyes are brown; antennæ black, rather short, reaching barely to the abdomen and but 5-jointed; the two basal joints as usually; the 3rd joint is longest, about as long as the remaining joints together, including the spur, with some projecting sensoria and a few short hairs; joints 4 and 5 are subequal in length, exclusive of the spur, and clavate, the spur is about ½ the length of the basal section of the joint, rather stout and blunt; the front of the head resembles that of *Aphis*. The sides of the abdominal segments are somewhat angulated, each angle provided with a very short, capitate, stout bristle, while at the posterior edge of the two segments, following the nectaries, there is a pair of long, diverging, fleshy spines, with a sharp, quite long and slender spine at the tip; the posterior pair longest; all of them black; the end of the body is fringed with fine and quite long hairs. Legs as in other Aphides.

The apterous females are dark brownish or grayish green above, with a somewhat fusiform median, yellowish strip, broadest near the head, tapering posteriorly to a point and terminating in front of nectaries; the sutures of the segments, the sides and under side of the body are also of a yellowish color, on account of which, there is each side a subdorsal row of transverse, dark spots. The head and about basal half of the antennæ, dark, dirty yellowish, the eyes dark brown. There are about 4 short and curved capitate hairs on the front of the head and prominent fleshy tubercles each side of the body, each bearing at its apex a short, capitate spine or hair, all of them growing longer toward the nectaries, while beyond the nectaries there are two pairs of long and slender fleshy tubercles, tipped with a spine, as in the migrant. A tail could not be seen. In the younger forms and pupae, the tubercles are as in the apterous female. In the pupae the head, prothorax, abdomen and nectaries are of a dirty yellowish color, with transverse rows of small, black or dusky spots on the abdomen. The wing pads are black.

Genus CERVAPHIS Van der Goot.

Plate VIII, G.

1916. *Cervaphis* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 148.

Characters.—Body armed with a series of long toothed projections; antennæ of apterous form five-segmented, of the alate form six-segmented with somewhat oval sensoria. Fore wings with the media once branched; hind wings greatly reduced in size and lacking both the media and cubitus; cornicles elongate, subcylindric. Cauda and anal plate reduced. Oviparous females often winged.

Type (fixed by Van der Goot, 1916), *Cervaphis schoutedeniae* V. d. Goot.

Subtribe MACROSIPHINA.

The genera of the subtribe Macrosiphina may be separated at once from those of the Aphidina in that they have developed large antennal tubercles. These may assume various shapes by which the genera often may be separated. Considerable variation is met with also in the cornicles and cauda, although as a rule the cornicles are very well developed. They may be either cylindrical or swollen. In one genus, Hyalopteroides Theo., the cornicles are very short, suggesting some of the genera of the Aphidina. The cauda is as a rule rather long. The wings are in nearly every case normal in venation. The different genera may be separated by the following key:

Key to the Genera of the Macrosiphina.[1]

1. Cornicles swollen .... 2.
   Cornicles cylindrical or tapering, scarcely swollen .... 6.

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[1] Since this paper was set up Takahashi (Insect World, v. 23, p. 439) has erected the following genus, which will fall in this subtribe.

Genus AKKAIA Takahashi.

Characters.—Cornicles swollen; frontal tubercles and first antennal segment with prominent projections. Antennæ of five segments. Cauda somewhat knobbed, anal plate large and projecting.

Type (monotypical), *Akkaia polygine*, Takahashi.

2. Cornicles cylindrical at base and extremity; abruptly swollen in middle.. Rhopalosiphoninus.
   Cornicles with the swelling gradual.................................... 3.
3. Head with a large central process on vertex........................Francoa.
   Head without this.. 4.
4. Antennal tubercles large and diverging.................................. 5.
   Antennal tubercles converging; head and basal antennal segments with very prominent capitate hairs..................................Capitophorus.
5. Cornicles much longer than cauda which is somewhat tapering..Amphorophora.
   Cornicles about the length of cauda which is usually constricted near its base...Megoura.
6. Cornicles very small, much smaller than the long, broad cauda..Hyalopteroides.
   Cornicles as long as or longer than the cauda.......................... 7.
7. Head with prominent, elongate projections to the antennal tubercles, particularly evident in the apterous form..........................Phorodon.
   Head without these.. 8.
8. Tubercles strongly converging..Myzus.
   Tubercles distinctly diverging.. 9.
9. Cornicles thick, about as long as the cauda which is large and somewhat constricted near base.................................Macrosiphonella.
   Cornicles very long, rather slender, subcylindric, somewhat tapering...... 10.
10. Cauda elongate, constricted near base............................Macrosiphum.
   Cauda moderate or elongate, not constricted near base.................. 11.
11. First antennal segment and abdominal segments with long fingerlike tubercles in the apterous form....................................Acanthaphis.
   Without these..Illinoia.

Genus ACANTHAPHIS Matsumura.

Plate VII, R-U.

1918. *Acanthaphis* Matsumura, Trans. Sapporo Nat. Hist. Soc., v. 7, pt. 1, p. 15.

The genus Acanthaphis Mats. is somewhat related to Phorodon.

Characters.—Head with prominent diverging antennal tubercles. Antennæ of six segments, first segment with a long fingerlike projection in the apterous form. Cornicles long, slender, and cylindrical. Cauda elongate, conical. Dorsum of abdomen with long fingerlike tubercles. Body with capitate hairs.

Type (fixed by Matsumura, 1918), *Acanthaphis rubi* Mats.

Genus AMPHOROPHORA Buckton.

Plate IV, A, B.

1876. *Amphorophora* Buckton, British Aphides, v. 1, p. 187.
1886. *Macrosiphum* Oestlund, Minn. Geol. Survey Rept. 14, p. 27.
1900. *Macrosiphum* Del Guercio, Nuove Rel. Staz. Firenze, ser. 1, no. 2, p. 159.
1901. *Nectarosiphon* Schouteden, Ann. Ent. Soc. Belg., v. 45, p. 112.
1913. *Eunectarosiphon* Del Guercio, Redia, v. 9, p. 188.
1913. *Rhopalosiphum* Van der Goot, Tijd. voor Ent., v. 56, p. 146.

Buckton erected his genus Amphorophora for his *ampullata* which he had secured in the apterous form only. Oestlund gave the generic name Macrosiphum to a species he described as *rubicola*. In his second paper Oestlund describes a species under the name *ampullata* Buckton and says:[1] "The length of the antennæ, together with the distinct frontal tubercles, may justify our exception of Amphorophora as a good genus." In speaking of his Macrosiphum

[1] Bul. 4, Geol. and Nat. Hist. Surv. Minn., p. 77, 1887.

Oestlund says it may be too close to Rhopalosiphum and compares it with *nymphaeae*. But had he compared it with *ampullata* which he also included in Rhopalosiphum he would probably have found it quite similar, and it is the writer's belief that Oestlund's species is in reality Amphorophora.

Finding that Macrosiphum was preoccupied Schouteden gave the new name Nectarosiphon to *rubicola* and Nectarosiphon, therefore, will become a synonym. In 1913, Del Guercio erected the genus Eunectarosiphon with *rubi* Kalt. as type. There appears not to be sufficient difference here, however. The insects are in their main points the same and Eunectarosiphon is placed, consequently, as a synonym. Van der Goot in the same year used *ampullata* as the type of Rhopalosiphum.

In 1900 Del Guercio used the name Macrosiphum for a genus including three species: *Convolvuli* Kalt., *viciae* Kalt., and *rubi* Kalt. He has since used both *viciae* and *rubi* as the types of other genera. This leaves only *convolvuli* in his Macrosiphum, and this species to all appearances is an Amphorophora. His Macrosiphum, therefore, is listed here under Amphorophora.

Characters.—Head with prominent and slightly diverging antennal tubercles. Antennæ of six segments, armed with circular sensoria. Wing venation normal. Cornicles long and somewhat swollen in the middle. Cauda elongate but much shorter than the cornicles.

Type (monotypical), *Amphorophora ampullata* Buckton.

Genus CAPITOPHORUS Van der Goot.

Plate VIII, A–C.

1913. *Capitophorus* Van der Goot, Tijd. voor Ent., v. 56, p. 84.

In the genus Capitophorus Van der Goot certain species suggest Rhopalosiphum in general characters, whereas others more nearly approach Myzus in their main characters. The capitate spines appear to be the best means of determining the genus.

Characters.—Head with antennal tubercles which are not markedly prominent, these each with one or more prominent knobbed spines. Vertex with a central projection on which similar spines are located. Antennæ of six segments, armed with subcircular sensoria, the first segment with a projecting process on which one or more knobbed spines are located. Wing venation normal; cornicles long and slender, slightly constricted in the middle and somewhat enlarged toward the distal extremity. Cauda rather short and conical.

Type (fixed by Van der Goot, 1913), *Aphis carduinus* Walker.

Genus FRANCOA Del Guercio.[1]

1917. *Francoa* Del Guercio, Redia, v. 12, p. 201.

The genus Francoa Del Guercio appears very close in some respects to Capitophorus but on account of the peculiar frontal tubercle and the structure of the first antennal segment it is held to be distinct.

[1] It seems doubtful if this genus is distinct from Capitophorus. We have been unable to make a careful study of the type.

Characters.—Head with antennal tubercles present. Vertex with a prominent rectangular process, both the antennal tubercles and the frontal process armed with knobbed spines. Antennæ of six segments, the first segment lacking the process and capitate hairs of *Capitophorus*. Cornicles rather slender and swollen near the distal extremity. Cauda elongate, somewhat conical.

Type (monotypical), *Francoa elegans* Del Guercio.

Genus HYALOPTEROIDES Theobald.

1916. *Hyalopteroides* Theobald, The Entomologist, v. 49, p. 51.

The genus Hyalopteroides was erected by Theobald for his species *pallida* found in the nest of *Lasius niger*, Porlock Weir, Somerset. It bears a striking resemblance to Pergandeidia but there are no prominent antennal tubercles in that genus. However, there are slight swellings suggestive of those figured by Theobald. The writer has never seen specimens of *pallida* and therefore is unable to give a personal opinion. Theobald says, "Head with marked frontal tubercles." This would place the genus as not closely related and pending a study of specimens it may be left thus.

Characters.—Head with prominent antennal tubercles. Antennæ of six segments and armed with subcircular sensoria. Cornicles subcylindric, short, much shorter than cauda. Cauda long and conical.

Type (monotypical), *Hyalopteroides pallida* Theo.

Genus ILLINOIA Wilson.

Plate VIII, H-J.

1910. *Illinoia* Wilson, Ann. Ent. Soc. Am., v. 3, p. 318.
1914. *Metopeurum* Mordwilko, Faune de la Russie, Hemiptera, , v. 1, p. 56, 67.
1914. *Acyrthosiphon* Mordwilko, Faune de la Russie, Hemiptera, v. 1, p. 55, 62.

This genus is closely related to Macrosiphum Pass. from which it may be distinguished by the nature of the cauda.

Characters.—Head with prominent diverging frontal tubercles. Antennæ of six segments armed with subcircular sensoria. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cornicles cylindrical, sometimes slightly larger toward the middle which appearance is accentuated by a constriction often present near the distal extremity. Cauda conical, not as in Macrosiphum with a constriction near its base. Males usually winged, oviparous females apterous.

Type (fixed by Wilson, 1910), *Siphonophora liriodendri* Mon.

Genus MACROSIPHONIELLA Del Guercio.

Plate VIII, R-T.

1911. *Macrosiphoniella* Del Guercio, Redia, v. 7, p. 331.
1913. *Macrosiphum* Van der Goot, Tijd. voor Ent., v. 56, p. 145.
1914. *Dielcysmura* Mordwilko, Faune Russ. Aphidodea, p. 56.

The genus Macrosiphoniella was erected by Del Guercio with *atrum* Ferr. as type. In 1913 Van der Goot used Macrosiphum of Passerini, indicating *millefolii* Fab. as type. This species can not be made the type of Macrosiphum Pass., and since it is essentially like *atrum*, V. d. Goot's Mascrosiphum must become a synonym of Macrosiphoniella. In 1914, Mordwilko used the generic name Dielcysmura for *millefolii* and figured the species. This name then proves also to be a synonym.

Characters.—Head with prominent diverging antennal tubercles. Antennæ of six segments armed with subcircular prominent sensoria. Fore wings with the media twice branched, hind wings with both media and cubitus present. Cornicles short, about the length of the cauda and rather thick, usually with conspicuous polygonal markings; cauda large, slightly constricted near the base.

Type (fixed by Del Guercio, 1911), *Aphis atrum* Ferr.

Genus MACROSIPHUM Passerini.

Plate VIII, U–W.

1860. *Macrosiphum* Passerini, Gli Afidi, p. 27.
1855. *Siphonophora* Koch, Die Pflanzenlaüse Aphiden, p. 150.
1887. *Nectarophora* Oestlund, Minn. Geol. Survey Bul. 4, p. 78.
1913. *Macrosiphon* Del Guercio, Redia, v. 9, p. 188.

In 1855 Koch used the generic name Siphonophora for this genus for which Passerini substituted Macrosiphum. Not aware of this Oestlund, seeing that Siphonophora was preoccupied, substituted Nectarophora and strangely enough used Macrosiphum for another genus in a different sense. Del Guercio uses Macrosiphon in this sense.

Characters.—Head with prominent diverging frontal tubercles. Antennæ of six segments, armed with subcircular sensoria. Fore wings with the media twice branched; hind wings with both media and cubitus present. Cornicles long, subcylindrical, mostly somewhat tapering; cauda long, somewhat constricted about the middle. Sexes with the male usually alate and the oviparous form apterous.

Type (fixed by Passerini, 1860), *Aphis rosae* Linn.

Genus MEGOURA Buckton.

1876. *Megoura* Buckton, British Aphides, v. 1, p. 188.
1913. *Drepaniella* Del Guercio, Redia, v. 9, p. 188.

The genus Megoura Buckton is similar to Amphorophora in that prominent antennal tubercles are present. It differs, however, in that the cornicles are short, about equal in length to the cauda. Buckton erected the genus for his *viciae* which Schouteden considered the same as *viciae* Kaltenbach. It certainly is very similar in every respect.

Viciae Kalt. was set as the type of his genus Drepaniella by Del Guercio, therefore Drepaniella will become a synonym of Megoura.

Characters.—Head with distinct antennal tubercles. Antennæ of six segments, armed with subcircular sensoria. Wing venation normal; cornicles moderately long and swollen in the middle. Cauda about the same length as the cornicles.

Type (monotypical), *Megoura viciae* Buckton.

Genus MYZUS Passerini.

Plate VIII, L, M, X–Z.

1860. *Myzus* Passerini, Gli Afidi, p. 27.
1860. *Rhopalosiphum* Passerini, Gli Afidi, p. 27.
1913. *Myzoides* Van der Goot, Tijd. voor Ent., v. 56, p. 84.
1913. *Ovatus* Van der Goot, Tijd. voor Ent., v. 56, p. 84.
1914. *Myzodes* Mordwilko, Faune Russ. Aphidoidea, p. 52.
1914. *Aulacorthum* Mordwilko, Faune Russ. Aphidoidea, p. 58.
1916. *Neomyzus* Van der Goot, Zur Kennt. der Blattläuse Java's, p. 50.
1918. *Myzopsis* Matsumura, Trans. Sapporo Nat. Hist. Soc., v. 7, pt. 1, p. 19.

The genus Myzus was erected with *Aphis cerasi* Fab. as type. In the same year Passerini used *Aphis persicae* Sulz. as type of Rhopalosiphum Koch. *Aphis nymphaeae* L., however, had been set as the type of that genus in 1856. *Persicae* seems to be very closely related to *cerasi* and Rhopalosiphum (Koch) Pass., therefore, is placed as a synonym of Myzus.

In 1913 Van der Goot placed certain other species in Myzus and the type of the genus he made the type of his Myzoides. This will evidently then become a synonym, as it has the same type.

In 1916 Van der Goot erected the genus Neomyzus with *circumflexum* Buckt. as type. While the frontal tubercles of this species do not converge quite to the same extent as those of *cerasi*, they are quite similar and the cauda is somewhat conical as in that species. Neomyzus, therefore, is believed to be a synonym. Mordwilko used the name Myzodes with *tabaci* Mord. as type. This species he does not fully describe, but gives a figure and describes the characters of the genus. From the information given it appears to be a synonym of Myzus. The writer also believes that the genus Ovatus V. d. Goot is a synonym of Myzus. This genus was erected with *mespili* V. d. Goot as type. The genus Aulacorthum Mord. was erected with *pelargonii* as type. A study of this species shows the antennal tubercles very similar to those of *cerasi*. The cornicles, too, are quite similar, although the cauda is a little more Aphis-like. The writer believes this genus is a synonym.

Characters.—Head with distinct antennal tubercles present which, particularly in the apterous form, project inward and are strongly gibbous. Antennæ of six segments, the first segment gibbous like the antennal tubercles. Wing venation normal. Cornicles rather long and subcylindrical. Cauda somewhat short and conical, constricted very slightly, if at all.

Type (fixed by Passerini, 1860), *Aphis cerasi* Fab.

Genus PHORODON Passerini.

Plate VIII, N–Q.

1860. *Phorodon* Passerini, Gli Afidi, p. 27.

Characters.—Head in the alate form with distinct antennal tubercles which project somewhat inward, first antennal segment gibbous. In the apterous form the antennal tubercles possess very prominent projections which extend forward in front of the head. First antennal segment with a projecting process. Fore wings with media twice branched; hind wings with both media and cubitus present. Cornicles cylindrical, in the apterous form somewhat curved; cauda rather acutely conical, not as long as the cornicles.

Males as a rule winged and oviparous females apterous.

Type (fixed by Passerini, 1860), *Aphis humuli* Schrk.

Genus RHOPALOSIPHONINUS, n. gen.

Plate IV, D–F.

The genus Rhopalosiphoninus is erected for *latysiphon* Davidson, a species with very peculiar cornicles. It appears to be somewhat related to Amphorophora.

Characters.—Head with prominent antennal tubercles which project inward and are armed with prominent spines. Antennæ of six segments armed with subcircular sensoria and in the first segment with spines similar to those of the antennal tubercles. Wing venation normal. Cornicles narrow and cylindrical at the base, then abruptly and prominently swollen, returning again abruptly to the normal size near the tip. Cauda rather short and conical.

Type, *Amphorophora latysiphon* Davidson.

Subtribe PENTALONINA.

The subtribe Pentalonina is one of the Aphidini in which specialization in the wing venation has taken place in a peculiar manner. The radial sector has in one genus extended downward and coalesced with the upper branch of the media. In the genus Idiopterus the two have not become entirely fused, though in some specimens they have almost done so. In Pentalonia, however, the veins have become permanently united, and a very peculiar-looking venation is the result. A closed cell is formed by the radial sector when it meets the upper branch of the media, and when it leaves this again it gives a three-branched appearance to the upper branch of the media. The explanation of this peculiar venation is, however, easily understood by comparison with the venation of Idiopterus. In some of the genera the hind wings are greatly reduced, so that sometimes only one vein remains, while in other genera this reduction has not taken place. Most of the wing veins are clouded with brownish borders.

The insects feed usually upon ferns or tropical plants.

KEY TO THE GENERA OF THE PENTALONINA.

1. Hind wings much reduced in size, lacking at least the cubitus .... 2.
   Hind wings nearly normal in size and with both media and cubitus present. 3.
2. Radial sector of fore wing fused with the upper branch of the media, forming a closed cell.. Pentalonia.
   Radial sector of fore wings not so fused, but normal .... Microparsus.
3. Cornicles cylindrical.. Idiopterus.
   Cornicles somewhat swollen near their distal extremities.................. 4.
4. Media of fore wings twice branched................................Fullawayella.
   Media of fore wings once branched................................Neotoxoptera.

Genus FULLAWAYELLA Del Guercio.

1911. *Fullawayella* Del Guercio, Redia, v. 7, p. 462.
1916. *Micromyzus*, Van der Goot, Zur Kenntniss der Blattlaüse Java's, p. 55.

This genus is very suggestive of Amphorophora in certain ways but no doubt is related here. Van der Goot's genus was erected with *nigrum* V. d. Goot as type but this species differs very little from *kirkaldyi*.

Characters.—Antennæ on prominent, converging, imbricated antennal tubercles, of six segments and armed with subcircular sensoria. Fore wings with the media twice branched and with the radical sector deeply curved toward the upper branch of the media; hind wings with both media and cubitus present. Cornicles somewhat swollen near their distal extremities. Cauda elongate and constricted near the base.

Type (monotypical), *Macrosiphum kirkaldyi* Fullaway.

Genus IDIOPTERUS Davis.

Plate VIII, EE-HH.

1900. *Idiopterus* Davis, Ann. Ent. Soc. Amer., v. 2, p. 198.

Idiopterus, a less specialized genus than Pentalonia, is worthy of special note, as it gives a key to the peculiar venation of the latter genus. The coalescing of the radial sector and the media is here plainly visible and in some specimens a triangular closed cell is formed, although in most examples the two veins can be traced distinctly.

Characters.—Head with prominent antennal tubercles which project slightly inwards, and are gibbous. Antennæ of six segments, armed with subcircular sensoria, the first segment gibbous like the antennal tubercles. Cornicles subcylindric, rather slender, cauda somewhat elongate, conical. Fore wings with the radial sector extending abruptly downward from the stigma and paralleling the upper branch of the media with which in some specimens it appears to be almost united; hind wings with both media and cubitus present.

Type (monotypical), *Idiopterus nephrolepidis* Davis.

Genus MICROPARSUS Patch.

Plate VIII, AA-DD.

1909. *Microparsus* Patch, Ent. News, v. 20, p. 337.

Microparsus is at once distinguished from the other genera related to it by the peculiar venation and the reduction of the hind wing.

Characters.—Head with distinct antennal tubercles present. Antennæ of six segments, armed with subcircular sensoria. Fore wings with the media once branched; hind wings much reduced in size and lacking both the media and cubitus. Cornicles subcylindric. Cauda rather long and tapering, almost equal in length to the cornicles.

Type (monotypical), *Microparsus variabilis* Patch.

Genus NEOTOXOPTERA Theobald.[1]

1915. *Neotoxoptera* Theobald, Bul. Ent. Res., v. 6, p. 131.

This genus is closely related to Fullawayella, from which it can be separated by the venation. There has been some doubt whether or not this is a good genus, for the name will not hold if the type is found to correspond with Pergande's *violae*, which it resembles. In that case Neotoxoptera would become a synonym of Fullawayella, for Pergande's species is undoubtedly a Fullawayella.

Characters.—Head with prominent antennal tubercles. Antennæ of six segments, armed with subcircular sensoria. Fore wings with the media once branched. Cornicles swollen, elongate, somewhat conical.

Type (monotypical), *Neotoxoptera violae* Theo.

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[1] After this paper was in type the writer (Bul. Ent. Res., v. 10, p. 45) showed that *violae* Theo. is a synonym of *violae* Perg.

Genus PENTALONIA Coquerel.

Plate VIII, II–MM.

1859. *Pentalonia* Coquerel, Ann. Ent. Soc. France, Ser. 3, v. 7, p. 259.

The genus Pentalonia Coquerel is a very peculiar one and possesses a venation unlike that of any other in the Aphididae. It is, however, only a little further development of the condition met with in Idiopterus, which is the less specialized of the two genera.

Characters.—Head with prominent antennal tubercles which are, more especially in the apterous form, projected inward, gibbous and somewhat Myzus-like in appearance. Antennæ of six segments, armed with subcircular sensoria, the first segment gibbous like the antennal tubercles. Cornicles somewhat constricted near their middle, then again somewhat swollen near their distal extremity. Cauda rather small but elongate, subconical, slightly constricted about the middle. Fore wings with the radial sector extending abruptly downward and meeting the upper branch of the media with which it fuses but is diverted again toward its natural course near the tip of the wing. A closed cell is thus formed by the radial sector and the media but at the margin of the wing there are the same veins as in the Aphidini (Plate VIII, JJ.) Hind wings very much reduced, cubitus absent.

Type (monotypical), *Pentalonia nigronervosa* Cql.

Subfamily II, MINDARINAE.

It has been the custom to consider the genus Mindarus as closely related to the Pemphigini, but the writer is unable to do this and concludes that it must represent a subfamily in itself. In some ways *abietinus* is the most primitive living aphid. It is, in fact, the only one which has retained the general wing structure which is predominant in the fossil forms. It is true that the venation is more reduced than in some of the other subfamilies, but the type of wing in regard to the stigma formation is exactly like most fossil wings and unlike the wings of other living forms. Many of the characters suggest the Eriosomatinae and the genus is no doubt very similar to the ancestors of the insects in that subfamily. The antennal structure and general form are like those in the Eriosomatinae. The sexes, too, are apterous, but though they have developed the small apterous condition they are in many ways more primitive than are the sexes of the Eriosomatinae. The male is small and suggests the condition in those forms. The peculiar habit of copulation is similar, in that the male mounts the female and may remain there inactive for a very long period. The writer has observed a male of *Eriosoma lanigerum* clinging thus to a female for 48 hours. The sexes of Mindarus, however, have not lost the beak and the male feeds on the juices of its host. In this regard they are more primitive than sexes in the Eriosomatinae. The oviparous female, moreover, develops her ovaries and produces as high as 8 or 9 eggs, in striking contrast with the ovipara in the Eriosomatinae. It is a much less specialized condition. In regard to the alate form the shape of the cauda is quite different from that met with in the Eriosomatinae.

It seems to the writer that the Mindarinae give a fair idea of the ancestors of the Eriosomatinae and may even represent a group dominant in earlier times from which the Eriosomatinae sprang.

Only one genus is represented.

Genus MINDARUS Koch.

Plate IX, A–F.

1857. Koch, Die Pflanzenläuse Aphiden, p. 277.

The peculiar genus Mindarus was erected by Koch with *abietinus* Koch as type. This species is the only one in the genus, although it has been redescribed as *Schizoneura pinicola* Thos. and *Schizoneura obliqua* Chol.

Characters.—Cornicles present as mere rings. Large wax plates present. Alate forms with six-segmented antennæ armed with oval sensoria. Fore wings with the media once branched; radial sector inserted mesad of the long narrow stigma, thus giving a very long stigmal cell; hind wings with both media and cubitus present. Cauda rather long, not rounded, but somewhat conical or even spatulate. Sexes small and apterous, beaks present and feeding taking place. Oviparous female with the ovaries developed and laying as high as 9 eggs. Forms living free upon the twigs of conifers which become somewhat distorted by the feeding of the insects.

Type (monotypical), *Mindarus abietinus* Koch.

Subfamily III, ERIOSOMATINAE.

The subfamily Eriosomatinae is composed of insects which are perhaps as specialized as any of the Aphididae. They show a remarkable development of the habit of gall formation and in this respect parallel the Hormaphidinae. The insects of that subfamily, however, evidently have developed the habit independently. Many previous authors have placed all of these forms in the present subfamily. This, the writer believes, is incorrect, as shown by the biologies of the insects. The sexual forms give a true understanding of the relationships and of the genera which should be included in the Eriosomatinae. All of the forms included by the writer show evidence of a common origin in that the sexes have become degenerate. They have become small apterous forms and have lost the mouth parts and the ability to take food. That this was not their original condition is clearly shown by the history of the family and also by the fact that the sexual forms of some species have a beak when born, but lose this at the first molting. Other species even at the time of birth are devoid of all but a rudimentary trophictubercle. The reproductive system of the female has become greatly altered. As previously pointed out by the writer, the early development of the reproductive system of the sexual female corresponds exactly to that in the apterous forms and to that of the oviparous forms of the more primitive groups.

Young embryos * * * show that the ovaries are at first similar to those of the parthenogenetic form. There may be distinguished the four chambers on each side containing egg cells and nutritive cells. In later embryos most of the egg tubes are in the process of degeneration and only two ovaries, one on each side, develop. Of these one finally degenerates and the egg of the other grows until it fills almost the entire body and the insect appears to be little else than egg.[1]

It will be seen at a glance that such a method of egg development is entirely different from that met with in members of the genera which have been heretofore placed in the subfamily. The Hormaphidini and the Thelaxini, as will be seen under the discussion of those tribes, have sexual females which develop normal ovaries and lay several eggs in the same way as do the Aphidini, Lachnini, and other groups. It is true that some have developed gall formation and highly specialized, wax-secreting organs, but this is more of a parallelism than a close relationship, as is indicated by the sexual forms. The wax-secreting organs of the Eriosomatinae vary considerably in structure. A study of those in the genus Eriosoma has been presented by the writer (1915). The glands here are compound, each cell containing a central wax chamber into which the wax is secreted and from which it is forced out as a fine waxen thread. In other genera the wax glands take on the nature of plates, illustrated in the genus Prociphilus. These glands are essentially the same in general structure as are those in Eriosoma, but the wax cells are placed very close together and are so extremely elongate that their openings to the surface are very small. A large number of these gives the appearance of a more or less uniform plate. The structure, however, in the two genera follows the same lines.

The wing venation in this subfamily presents as great a reduction as in any of the subfamilies of the Aphididae and in this respect it is comparable to the Hormaphidinae. In the fore wings the reduction is shown in the media which is never branched more than once. Dr. Patch has pointed out the homologies of the veins and has indicated that in all of these cases the branches represent M_{1+2} and M_{3+4}. In some cases, however, it would appear as if they were M_1 and M_4. In other genera the media is indicated as a single vein. The radial sector is in nearly every case present and the cubitus and first anal are prominent veins. The tracheae are figured for the subfamily under the genus Eriosoma. In the hind wings the radial sector is always present and two oblique veins are nearly always found. These are the media and the cubitus. In several genera, however, the cubitus has disappeared and only the media remains as the one transverse vein in the hind wings.

The cornicles in the genera of this subfamily are not prominently developed. Indeed, they are absent altogether in certain of the tribes. In the genus Eriosoma they are chitinized rings slightly elevated on shallow hairy cones. The opening of the cornicles is closed by a muscle and from the cornicle a narrow duct leads to a

[1] Baker, A. C. The woolly apple aphis. U. S. Dept. Agr., Off. of Sec., Rept. 101, p. 43. 1915.

large wax reservoir. The structure of the cornicles themselves in this subfamily is essentially the same in all genera where they are present. In a large number of genera, however, the wax reservoir is absent and in some specialized tribes the cornicles are likewise absent. It is interesting to note that in some genera, though absent in the stem mother, they are present in the alate forms.

The habit of gall formation is not found equally in all genera and it would seem that those forms which have become associated with ants have not developed this habit to the same extent as have some of the other groups. However, it must be borne in mind that our knowledge concerning the species associated with ants is very incomplete, and the writer is convinced that many of the Prociphilini will be found during their summer generations in this relation. Many of the forms cause true galls which are the result of outgrowths of the plant and which completely enclose the insects. Sometimes the stem mother lives in a gall by herself while in other cases the following generations live with her. The original spring gall is usually the result of the activities of the young stem mother. Certain species do not produce true galls but form pseudogalls which are due to the rolling or crumpling of the leaves on which the insects feed. Other species, again, especially during their summer generations, feed on the twigs or roots of plants and give rise to excrescences by their feeding. It often happens that species which in their spring forms are gall makers, attack plants in this way in their summer generations. Others live on the roots of grasses during these generations and do not cause the excrescences produced by those species feeding on trees and woody shrubs.

The association with ants is highly developed by one tribe of this subfamily, although all of the other tribes are to a degree tended by these insects. The species of the Fordini live exclusively in the nests of ants or are tended by them, and they are cared for very carefully in return for the honeydew excreted. Ants also attend species which have aerial feeding habits and they may be seen carrying the root generations of species of Eriosoma from one place to another and even distributing them about on the trees. Indeed the writer once took advantage of the presence of ants to infest some apple seedlings. A vial of apterous insects was emptied at the base of each tree and the ants soon could be seen running about carrying the aphids to suitable positions on the trees. Sometimes, however, they carried them away.

KEY TO THE TRIBES OF THE ERIOSOMATINAE.

1. Cornicles present, at least in the alate forms; however, often mere rings.... 4.
   Cornicles absent.... 2.
2. Forms living in true galls or in pseudogalls on plants.... 3.
   Forms living in the nests of ants or at least subterranean, feeding on the roots of plants; wax-secreting areas present; antennæ of alate forms rather short and thick with somewhat oval sensoria....FORDINI.
3. Forms living in true galls and without wax plates prominently developed on the head and thorax of alate form; wax-secreting areas present but not prominently developed. Alate forms leaving the galls in the late summer or fall. Antennæ with annular sensoria....MELAPHINI.
   Forms living in pseudogalls, occasionally in true galls. Antennæ of alate form rather long and slender, with narrow or somewhat oval or rounded sensoria. Wax plates well developed and present on the head and thorax of the alate forms which leave the galls in the spring....PROCIPHILINI.
4. Forms living in galls, pseudogalls, or free upon their host; wax glands prominently developed; antennæ of alate forms armed with annular sensoria which almost completely encircle the segments....ERIOSOMATINI.
   Forms living usually in true galls; wax glands present but not strongly developed; antennæ of alate forms armed with narrow, transverse sensoria, somewhat oval or irregular ones, or occasionally without sensoria..PEMPHIGINI.

Tribe ERIOSOMATINI.

The tribe Eriosomatini is composed of insects which have more or less developed the habit of gall formation, which are possessed of wax glands, and the antennæ of the alate forms of which are armed usually with annular sensoria. Their typical host group is that of the elms.

Characters.—Forms living in galls, pseudogalls, or free upon the twigs or roots of their host on which they form excrescences. Prominent wax glands present. Cornicles distinct; antennæ of alate forms armed with annular sensoria which often almost completely encircle the segments. Sexual forms small, apterous, beakless; oviparous females developing a solitary egg.

KEY TO THE GENERA OF THE ERIOSOMATINI.

1. Media of the fore wings of alate form once branched.... 3.
   Media of the alate form simple.... 2.
2. Hind wings with both media and cubitus present.... Gobaishia.
   Hind wings with only the media present.... Tetraneura.[1]
3. Hind wings with both media and cubitus present.... Eriosoma.
   Hind wings with only the media present.... 4.
4. Stem mother with four-segmented antennæ; antennæ of alate form rather short and thick.... Colopha.
   Stem mother with five-segmented antennæ; antennæ of alate form long and slender.... Georgia.

[1] There is considerable evidence for separating a tribe Tetraneurini to include the genera Colopha, Tetraneura, and Gobaishia.

Genus COLOPHA Monell.

Plate IX, G–L.

1877. *Colopha* Monell, Can. Ent., v. 9, p. 102.

The genus Colopha was erected for *ulmicola* Fitch. One of the principal characters whereby it may be separated from Tetraneura is the once-branched character of the media. The two genera, however, are very closely related. The species have the same peculiar structure and the same mode of life.

Characters.—Cornicles slightly elevated rings. Stem mother with four-segmented antennæ. Apterous form with five-segmented or sometimes six-segmented antennæ. Wax glands present. Alate form with six-segmented antennæ which are armed with annular sensoria partly encircling the segments. Fore wings with the media once branched, hind wings with only the media present. Forms making galls upon the leaves of trees in which the stem mother and her offspring live in company; in summer migrating to the roots of plants.

Type (monotypical), *Byrsocrypta ulmicola* Fitch.

Genus ERIOSOMA Leach.

Plate IX, M–T.

1818. *Eriosoma* Leach, Trans. Hort. Soc. London, v. 3, p. 60.
1831. *Myzoxylus* Blot, Mem. Soc. Roy. Agr. et de Com. Caen., v. 3, p. 332.
1837. *Schizoneura* Hartig, Jahresb. ü. d. Fortschr. d. Forstwiss. und forstl. Naturk., v. 1, p. 645.
1848. *Mimaphidus* Rondani, Nuovi Annali della Scienze Naturali, ser. 2, v. 9, p. 35.

In 1818 Leach erected his genus in a footnote in connection with a paper read by Mosley. The paper was published in 1818. In 1819 Samouelle published his "Useful Compendium" and on page 232 characterized the genus Eriosoma Leach MSS. The printed copy of the Transactions appeared complete in 1820. In 1824 Blot used the word Myzoxyle which he corrected to Myzoxylus in 1831. For these *Aphis lanigera* Hausm. was used as type.

In 1837 Hartig erected Schizoneura and of this genus *ulmi* was made type by Passerini in 1860. This then will become a synonym. *Corni* Fab. was for a time considered the type of this genus but this species was not in the original genus. In 1848 Rondani used Mimaphidus with *ulmi* Fab. as type, which according to Passerini is the same as *lanuginosa* Hartig. Therefore, this genus will become a synonym.

Characters.—Cornicles distinct rings on somewhat elevated tubercles. Apterous form with six-segmented antennæ. Stem mother with five-segmented antennæ. Wax plates present in the apterous and alate vivipara. Alate form with six-segmented antennæ armed with annular sensoria. Fore wings with the media once branched, hind wings with both media and cubitus present; cauda and anal plate rounded. Forms living in gall-like formations or causing excrescences on their hosts. Sexual forms small, apterous, beakless. Only one egg of those of the oviparous female develops.

Type (monotypical), *Aphis lanigera* Hausmann.

Genus GEORGIA Wilson.

Plate IX, U-Z.

1911. *Georgia* Wilson, Can. Ent., v. 43, p. 64.

The genus Georgia appears to be related to Colopha Mon., and yet many of the characters are so like those of Eriosoma that the insect suggests that genus also. Especially to the species *E. americanum* Riley there is a striking resemblance. Prominent wax glands are lacking but these are sometimes also lacking in the spring forms of Eriosoma.

Characters.—Cornicles present and situated on shallow hairy cones as are those of Eriosoma. Stem mother with five-segmented antennæ; alate form with six-segmented antennæ which are armed with narrow sensoria that do not encircle the segment to any extent. Fore wings with the media once branched, hind wings with only one oblique vein. Cauda rounded. Prominent wax pores such as those present in Eriosoma lacking, but small wax areas present.

Forms living in pseudogalls on plants, the alate individuals migrating from the galls in the early spring.

Type (monotypical), *Georgia ulmi* Wlsn.

Genus GOBAISHIA Matsumura.

Plate X, A-G; XI, V.

1909. *Byrsocrypta* Tullgren, Arkiv för Zoologi, Bd. 5, no. 14, p. 182.
1917. *Gobaishia* Matsumura, Synopsis of the Pemphigidae of Japan, Gifu, Japan, p. 75.

Tullgren used the name Byrsocrypta Hal. as the name of a subgenus with *pallida* as type, placing it under Tetraneura. He apparently overlooked the fact that Westwood had set *bursarius* as the type of the genus Byrsocrypta as will be found discussed under the genus Pemphigus. *Pallida* is different from the species of Tetraneura, in that the cubitus is retained in the hind wing. If *Colopha* is retained on account of the branched nature of the media in the fore wings it will be necessary to place *pallida* as typical of a genus related to Tetraneura.

In 1917 Matsumura erected the genus Gobaishia with *Gobaishia japonica* Mats. as type. This species was stated to be very similar to *Tetraneura alba* Ratz. *Tetraneura alba* Ratz is the same species as *Eriosoma pallida* Haliday and the characters given for the genus are, therefore, similar to Tullgren's conception of Byrsocrypta. The figures drawn are from specimens of *pallida* as no *japonica* was available to the writer for study.

Characters.—Cornicles present, stem mother with four-segmented antennæ, alate forms with six-segmented antennæ which are armed with annular sensoria. Fore wings with the media usually simple; hind wings with both cubitus and media present.

Type (fixed by Matsumura, 1917), *Gobaishia japonica* Mats.

Genus TETRANEURA Hartig.

Plate X, H–M.

1841. *Tetraneura* Hartig, Germar's Zeitschrift für die Entomologie, v. 3, p. 366.

In 1841 Hartig erected the genus Tetraneura under which he gave *Tetraneura ulmi* Lin. ? questioned thus and described. He also listed *T. rugicornis* Hartig. One of these species was questioned and the other merely listed. *Ulmi* L., however, was questioned only in the sense of the determination, and a good description was given so that it is known what insect Hartig had.

In 1843 Kaltenbach gave a description of the genus Tetraneura crediting it to Hartig and described thereunder one species, *Aphis ulmi* De Geer. *Aphis ulmi* De Geer (1773) is the same species as *Aphis ulmi* Geoffroy (1764) but this name can not be used, since Linnaeus used *Aphis ulmi* for a different insect. This is the same insect described by Hartig as *T. ulmi* L. ? and it is evident that it requires a new name, to which *ulmifoliae* is given.

Characters.—Cornicles very slightly elevated rings, not at all prominent. Stem mother with four-segmented antennæ; apterous form with five-segmented antennæ. Wax glands present. Alate form with six-segmented antennæ which are armed with narrow annular sensoria almost completely encircling the segment. Fore wings with the media simple; hind wings with only the media present.

Forms living in galls and migrating in spring to other plants. Sexes small, apterous and beakless. Oviparous female developing only one egg.

Type, *Tetraneura ulmifoliæ* Baker (*Aphis ulmi* L. of Hartig).

Tribe PEMPHIGINI.

The tribe Pemphigini is composed of forms which are highly specialized and most of which have developed the habit of true gall formation. The secretion of wax also occurs but wax secreting plates are not developed to the extent met with in some of the other tribes of the subfamily. Alternation of hosts is found to occur, migrants leaving the galls in early spring or summer and returning in autumn. In some species, however, the insects do not leave the galls until the mothers of the sexual forms are produced. Distinct cornicles are present and by this character forms in some of the other tribes which are suggestive of the Pemphigini may be distinguished. The typical host group is Populus and the galls are normally spring galls.

Characters.—Forms usually inhabiting true galls and often migrating to other plants during the summer. Antennæ of six segments in the alate form and in nearly all genera armed with linear, oval, or somewhat irregularly shaped sensoria. Small wax-secreting areas present. Sexual forms small, apterous, and beakless, the oviparous female developing only one egg.

Six genera may be included in the tribe and these genera may be separated by the following key:

Key to the Genera of the Pemphigini.

1. Unguis of segment VI of alate form distinctly long and Aphis-like..Mordwilkoja.
   Unguis short and knob-like........ 2.
2. Media once branched........ 3.
   Media simple........ 4.
3. Antennæ of alate form usually without secondary sensoria. Wings flat in repose........Phloeomyzus.
   Antennæ of alate form with secondary sensoria. Wings not flat in repose........Pachypappella.
4. Both media and cubitus present in hind wing........ 5.
   One oblique vein only in hind wing........Dryopeia.
5. Antennæ of alate form without secondary sensoria. Wings flat in repose........Rhizoctonus.
   Antennæ of alate form with secondary sensoria. Wings not flat in repose... 6.
6. Antennæ of alate form rather short and thick. Stem mother with four-segmented antennæ........Pemphigus.
   Antennæ of alate form rather long and slender. Stem mother with five-segmented antennæ........Cornaphis.

Genus CORNAPHIS Gillette.

Plate X, N–T.

1913. *Cornaphis* Gillette, Ann. Ent. Soc. Am., v. 6, p. 491.

The genus Cornaphis was erected by Gillette for his species *Cornaphis populi.* In his description it is stated that the genus is closely related to Asiphum. In Cornaphis, however, there are large cornicles in the alate form and in other respects it seems that the genus is closely related to Pachypappella. In that genus, however, the media is once forked, whereas in Cornaphis it appears to be simple, at least as a rule. This difference has led the writer to retain a genus with *lactea* as type rather than to place that species and similar ones in Cornaphis.

Characters.—Cornicles present; stem mother with five-segmented antennæ and without wax plates. Alate form with six-segmented antennæ armed with rather narrow sensoria; permanent sensoria ciliate. Fore wings with the media simple, hind wings with both media and cubitus present; wax plates present in the apterous form; sexes small, apterous and beakless; the oviparous female developing only one egg.

Forms living in galls, the stem mother and the following forms living in the same gall.

Type (monotypical), *Cornaphis populi* Gill.

Genus DRYOPEIA Kirkaldy.

Plate X, U–Y.

1857. *Endeis* Koch, Die Pflanzenläuse Aphiden, p. 312.
1889. *Eudeis* Ashmead, Ent. Amer., v. 5, p. 189.
1904. *Dryopeia* Kirkaldy, The Entomologist, v. 37, p. 279.
1917. *Watabura* Matsumura, Synopsis of the Pemphigidae of Japan, p. 89.

In 1857 Koch erected his genus Endeis with two species, *bella* Koch and *rorea* Koch. This name was replaced by Dryopeia in 1904 by Kirkaldy, and *bella* has been definitely placed as the type.

In some respects the genus is suggestive of Anoecia, although it seems to be undoubtedly a Pemphiginid and will no doubt be so proven by the sexual forms.

In 1917 Matsumura erected his genus Watabura with *Watabura nishiyae* Mats. as type. This species was stated to resemble a Pemphigus, excepting that the antennal segments are somewhat different and only one oblique vein is in the hind wing. (Two obliques are shown in his Pl. XII, 9). The antennæ are armed with narrow transverse sensoria and there seems little doubt that this genus is a synonym of Dryopeia. It is noteworthy that the life history of the type species is not known, but it is thought to live on the roots of trees. The type of the genus Dryopeia is a root feeder.

Characters.—Cornicles present, situated on broad shallow cones, suggestive of those of Anoecia. Stem mother unknown, apterous forms with six-segmented antennæ. Alate forms with six-segmented antennæ, armed with narrow transverse sensoria. Fore wings with media simple, hind wings with one oblique vein. Summer forms subterranean, living on the roots of plants. Spring forms and sexes unknown. Apterous tarsi one-segmented.

Type (fixed by Kirkaldy, 1906), *Endeis bella* Koch.

Genus MORDWILKOJA Del Guercio.

Plate XI, A–G.

1909. *Mordwilkoja* Del Guercio, Rivista Patol. Veget., v. 4, p. 11.

This genus was erected in 1909 for the peculiar species *Byrsocrypta vagabunda* Walsh. This differs in the antennæ quite remarkably from all of the other species belonging to this tribe. The difference is in the long unguis of the sixth segment. However, the other characters and the four-segmented nature of the antennæ of the stem mother seem to place it with little doubt in the Pemphigini.

There has been some doubt cast by Oestlund on the determination of Walsh's species and this has led Cockerell to propose the name *oestlundi* for the species now known so well, but, as Gillette has pointed out, Walsh evidently accepted the insect of Riley and Monell as the same species as his *vagabunda*. The insects Riley had were undoubtedly the species we know and the writer therefore accepts *vagabunda* and the generic name Mordwilkoja. The genus was erected with the name *vagabunda* used as type and not *oestlundi*.

Characters.—Cornicles present as somewhat elevated rings. Stem mother with four-segmented antennæ, the unguis of segment VI slender and Aphis-like. Permanent sensoria ciliate. Alate form with five-segmented antennæ which are armed with narrow transverse sensoria. Fore wings with the media simple, hind wings with both media and cubitus present.

Forms living in galls; the stem mother and her offspring living in the same gall, the alate forms leaving the galls in spring or early summer. Sexes unknown, but no doubt small, apterous, and beakless.

Type (monotypical), *Byrsocrypta vagabunda* Walsh.

Genus PACHYPAPPELLA, n. n.

Plate XI, H–M.

1909. *Pachypappa* Tullgren, Arkiv för Zoologi, Bd. 5, no. 14, p. 69.

In 1854 the genus Pachypappa was erected by Koch with *marsupialis* and *vesicalis* in the genus. A study of *marsupialis* shows that this species is in reality a Pemphigus as it shows all the characters of this genus. Tullgren, 1909, noted this and therefore interpreted the genus differently. *Marsupialis* had, however, been set as the type of the genus. Pachypappa Koch, therefore, becomes a synonym of Pemphigus, and Pachypappa Tullgren must receive a new name for which Pachypappella is here given.

Characters.—Stem mother without cornicles but with wax plates; antennæ five-segmented. Alate form with cornicles; antennæ six-segmented and with transverse sensoria. Fore wings with media once branched, hind wings with both media and cubitus present.

Type (present designation), *Pachypappa lactea* Tullgren.

Genus PEMPHIGUS Hartig.

Plate XI, N–U.

1837. *Pemphigus* Hartig, Jahresb. u. d. Fortschr. d. Forstwiss. und forstl. Naturk., v. 1, p. 645.
1839. *Byrsocrypta* Haliday, Ann. Nat. Hist., v. 2, p. 190.
1840. *Brysocrypta* Westwood, Int. Mod. Class. Ins., Synopsis, v. 2, p. 118.
1847. *Aphioides* Rondani, Nuovi Annali Sci. Nat. Bologna (2), v. 8, p. 439.
1857. *Amycla* Koch, Die Pflanz. Aphiden, p. 301.
1857. *Pachypappa* Koch, Die Pflanz. Aphiden, p. 269.
1857. *Rhizomaria* Hartig, Verhandl. d. Hils-Solling-Forstvereins, Jahrg. 1856, p. 52.
1859. *Tychea* Koch, Die Pflanzenlaüse Aphiden, p. 296.
1885. *Kessleria* Lichtenstein, Mon. Puceron du Peupl., p. 16.
1904. *Hamadryaphis* Kirkaldy, The Entomologist, v. 37, p. 279.

In 1837 Hartig erected his genus Pemphigus, although it was not until 1841 that his reference to the genus as generally cited appeared. Passerini in 1860 set *bursarius* as type. In 1839 Haliday used the generic term Byrsocrypta but mentioned no species. In 1840 Westwood referred to this genus as Brysocrypta and gave *bursaria* L. as type. In 1859 Koch erected the genus Tychea with *graminis* Koch as type (monotypical). Schouteden (1906) has described the winged form of *Tychea graminis* Koch and stated that it is a typical Byrsocrypta. The writer has had no opportunity to study specimens but on the strength of this statement of Schouteden places Tychea as a synonym of Pemphigus. It is worthy of note, however, that Schouteden did not mention the cornicles, and this is a point of considerable difference if *graminis* is a Pemphigus or if it belongs to the Fordini.

In 1857 Hartig described the genus Rhizomaria with *piceae* Hartig as type. This species, however, appears to be a typical Pemphigus and Rhizomaria will become a synonym.

In 1857 Koch erected the genus Amycla and of this genus *fuscifrons* Koch has been made the type. The writer has been unable to obtain specimens of this species but from the descriptions it seems almost certain that this species is a true Pemphigus. This will thus make the genus Amycla a synonym.

In 1847 Rondani described the genus Aphioides of which *bursaria* Fab. was indicated as the type and Aphioides, therefore, is a synonym.

In 1854 Koch erected the genus Pachypappa of which *marsupialis* Koch has been made the type. *Marsupialis*, however, is a typical Pemphigus. Pachypappa Koch, therefore, must become a synonym. Tullgren (1909) used Pachypappa in a different sense, but this is discussed under the genus Pachypappella.

In 1886 Lichtenstein erected the genus Kessleria for *spirothica* and this name was replaced by Hamadryaphis Kirk. in 1904. A study of this species, however, shows that it is a typical Pemphigus. Therefore, these two names will become synonyms.

Characters.—Cornicles present; wax plates, if present, weakly developed; stem-mother with four-segmented antennæ; alate form with six-segmented antennæ which are armed with narrow, oval or somewhat irregular sensoria. Fore wings with the media simple; hind wings with both media and cubitus present. Sexes small, apterous, and beakless. Oviparous female developing only one egg.

Forms living in galls, the stem-mother and her offspring in the same gall, the alate forms typically leaving the galls in the spring.

Type (fixed by Passerini, 1860), *Aphis bursaria* L.

Genus PHLOEOMYZUS Horvath.

Plate XI, W–BB.

1886. *Löwia* Lichtenstein, Mon. Puceron Peupl., p. 37.
1896. *Phloeomyzus* Horvath, Wien. Ent. Zeit., v. 15, p. 5.

In 1886 Lichtenstein erected the genus Löwia with *Schizoneura passerinii* Sig. as type but as this name had been used previously it was replaced in 1896 by Phloeomyzus Horvath.

It is with some hesitation that the writer places this genus in the Pemphigini. In some respects it suggests the Melaphini, while in many respects it strongly suggests the Thelaxini or even the Phyllaphidina. Indeed, to the Melaphini it shows striking resemblances. Without a study of the sexual forms it will be very difficult to place the genus definitely. All that can be done at the present time is to place it tentatively with the forms with which it appears to be related, and if further study shows this to be incorrect the genus can be placed definitely with its allies.

Characters.—Cornicles present, very slightly elevated. Apterous form with six-segmented antennæ. Alate form with six-segmented antennæ which are rather slender and without secondary sensoria. Fore wings with the media once branched, hind wings with both media and cubitus present. Large wax plates present on the abdomen. Wings held flat in repose.

Forms living free upon the bark of trees in colonies.

Type (monotypical), *Schizoneura passerinii* Sig.

Study based on specimens received from Mordwilko from Warsaw, Poland, and notes by Pergande on type specimens loaned by Horvath.

Genus RHIZOCTONUS Mokrzecky.

1895. *Rhizoctonus* Mokrzecky, Horae. Soc. Ent. Ross., v. 30, p. 438.

The genus Rhizoctonus was erected for *ampelinus* Mok., a species occurring on the vine. Through the kindness of H. F. Wilson the writer has been able to examine a slide containing alate forms. These, however, are in a very poor condition and it is impossible to determine whether or not cornicles are present. The antennæ too are much distorted. This slide seems to indicate, however, that *ampelinus* is somewhat related to *passerinii* Sig., an hypothesis which is strengthened by the fact that both species hold the wings flat in repose. The genus, therefore, is placed here with some hesitation.

Characters.—Antennæ of six segments, without secondary sensoria and rather thick. Fore wings with the media simple. Hind wings with both media and cubitus present. Wings held flat in repose. Cauda and anal plate rounded.

Type (monotypical), *Rhizoctonus ampelinus* Mok.

Tribe MELAPHINI.

The tribe Melaphini is suggestive both of the Pemphigini and of the Eriosomatini. It is, however, quite distinct from both. The habits more nearly resemble those of the Pemphigini. The tribe is placed here but a study of the sexes may show that it really belongs to the Hormaphidinae. The typical host group is Rhus, and the galls are typically fall galls.

Characters.—Gall-inhabiting forms. Cornicles absent; antennæ of the alate form of five or six segments armed with somewhat oval or linear transverse sensoria. Sexual forms not known.

The genera may be separated as follows:

KEY TO THE GENERA OF THE MELAPHINI.

1. Both media and cubitus present in the hind wings .... 2.
   Only the media present in the hind wings .... Aploneura.
2. Stigma of four wings pointed on distal portion and extending some distance .... Melaphis.
   Stigma stopping abruptly on distal extremity .... 3.
3. Antennæ of five segments .... Nurudea.
   Antennæ of six segments .... Pemphigella.

Genus APLONEURA.

Plate XII, A-E.

1863. *Aploneura* Passerini, Aphididae Italicae, p. 78.
1869. *Tetrenema* Derbès, Ann. des Sc. Nat. Zool. (5), v. 11, p. 106.
1848. *Baizongia* Rondani, Nuovi Annali delle Scienze Naturali, v. 9, p. 35.

The genus is distinguished quite easily from related ones by the venation of the hind wings, the relation of the cubitus and anal of the fore wings, and by the structure of the antennæ. The positive determination of the insect of Fabricius may cause Aploneura to fall for Rondani's name.

Characters.—Cornicles absent. Stem-mother with five-segmented antennæ; alate form with the media simple, the cubitus and anal joined near their bases. Hind wings with only the media present, antennæ of six segments, armed with large subcircular or elongate sensoria. Forms living in true galls.

Type (monotypical), *Tetraneura lentici* Pass.

Genus MELAPHIS Walsh.

Plate XII, F–K.

1866. *Melaphis* Walsh, Proc. Ent. Soc. Phila., v. 6, p. 281.
1883. *Schlechtendalia* Lichtenstein, Stett. Ent. Zeit., v. 44, p. 240.
1905. *Abamalekia* Del Guercio, Redia, v. 3, p. 364.

Walsh erected his genus for *rhois* Fitch, a species forming galls on sumach and in his discussion mentioned the Chinese gall, wondering if it could be congeneric. The writer has recently published an account of the Chinese gall[1] and therein placed Schlechtendalia Licht. as a synonym of Melaphis. Del Guercio's genus was erected with his *lazarewi* as type and placed as a thelaxine. Although the writer has never obtained specimens of this species he is of the opinion that it can not possibly be one of these insects and that it evidently belongs in the Melaphini where the shape of the stigma would immediately place it as a Melaphis.

Characters.—Cornicles absent. Apterous form with five-segmented antennæ. Alate form with either five or six segmented antennæ which are armed with somewhat linear or oval sensoria. Fore wings with the media simple, although sometimes slightly forked, distal extremity of the stigma rather long drawn out; hind wings with both media and cubitus present; abdomen with distinct wax plates. Forms living in galls from which the alate forms escape in late summer or fall.

Type (monotypical), *Byrsocrypta rhois* Fitch.

Genus NURUDEA Matsumura.

Plate XII, L–Q.

1917. *Nurudea* Matsumura, Synopsis of the Pemphigidae of Japan, p. 65.
1917. *Nurudeopsis* Matsumura, Synopsis of the Pemphigidae of Japan, p. 67.
1917. *Fushia* Matsumura, Synopsis of the Pemphigidae of Japan, p. 70.

Matsumura erected his genus Nurudea for his *Nurudea ibofushi*, a species somewhat similar to a species of Melaphis. This species differs quite markedly, however, in the form of the stigma. At the same time he erected the genus Nurudeopsis with *N. shiraii* as type. This species differs little from *ibofushi* excepting in the proportions of the segments, and in the fact that the cubitus and first anal are somewhat closer together at the base. The writer is of the opinion that these characters are not sufficient on which to form another genus. In the same work also he erected the genus Fushia with *Fushia rosea* Mats. as type. This species differs somewhat from the type of Nurudea but the writer believes that there are not differences sufficient to cause this to be considered as a separate genus. The antennæ

[1] Baker, A. C. On the Chinese gall (Aphididae—Hom.). *In* Ent. News, v. 28, p. 385–393, 1917.

are more slender and of somewhat different proportions and the cubitus and anal of the fore wings are united somewhat at base. In other genera, however, this difference between species is to be found, and it seems wisest not to adopt it in this group as of generic importance.

Characters.—Cornicles absent. Antennæ of five segments armed with linear or somewhat oval sensoria. Fore wings with the media simple, the stigma normal; hind wings with both media and cubitus present. Sexes unknown. Forms making galls upon the leaves of plants.

Type (fixed by Matsumura, 1917), *Nurudea ibofushi* Mats.

Genus PEMPHIGELLA Tullgren.

1909. *Pemphigella* Tullgren, Arkiv för Zool., v. 5, p. 171.
1918. *Dasia* Van der Goot, Mem. Ind. Mus., v. 6, p. 152.

Characters.—Cornicles absent. Antennæ of six segments armed with oval sensoria. Hind wings with both media and cubitus present. Sexes unknown. Species forming galls on plants. Type (monotypical), *Tetraneura cornicularia* Pass.

Tribe PROCIPHILINI.

The tribe Prociphilini contains forms which specialized in some directions more than did the Eriosomatini. In other ways, however, they appear to be more primitive than certain genera of that tribe. The cornicles have here disappeared altogether and large wax areas have replaced them. In their habits of gall formation, however, the Eriosomatini are more advanced than are members of the present tribe.

Characters.—Forms living in crumpled or twisted leaves or in a somewhat complete gall caused by the rolling up of the leaves of the host. Wax plates present; cornicles absent; antennæ of stem mother of five segments; those of the alate form six segmented and armed with narrow, transverse, or somewhat broadly oval sensoria.

KEY TO THE GENERA OF THE PROCIPHILINI.

1. Media once forked, stem mother usually without wax plates .... Asiphum.
   Media simple, stem mother with several rows of wax plates .... 2.
2. Wax plates large, those on the thorax well developed, stem mother and offspring living together .... 3.
   Wax plates not well developed, stem mother usually in a gall by herself .. Thecabius.
3. Sensoria narrow, linear, ciliate .... Prociphilus.
   Sensoria somewhat oval, nonciliate .... Neoprociphilus.

Genus ASIPHUM Koch.

Plate XII, R–X.

1857. *Asiphum* Koch, Die Pflanzenläuse Aphiden, p. 246.
1859. Type fixation, Gerstaecker, Bericht for 1857, p. 249.
1905. Type fixation, Kirkaldy, Can. Ent., v. 37, p. 418.

The genus Asiphum was erected by Koch with two species, *populi* Fab. and *ligustrinellum* Koch. He listed De Geer's work in the literature under *populi* Fab. The *populi* of Fabricius proves to be the *tremulae* of De Geer. Only the species *ligustrinellum* was placed in the genus by Lichtenstein (1885) and this species has been indicated as type of the genus by Kirkaldy (1905). *Tremulae* De Geer is a well-known species but the writer has been unable to obtain *ligustrinellum* and, in fact, has been unable to learn anything definite in regard to the species. The following conception of the genus, therefore, is based upon *tremulae* De Geer in view of the fact that *ligustrinellum* appears to be unknown, and since *Aphis populi* Fab. was indicated by Gerstaecker in 1859.

Characters.—Cornicles absent; wax plates present in the alate forms; stem mother with five-segmented antennæ. Alate form with six-segmented antennæ which are armed with rather narrow transverse sensoria. Fore wings with the media once forked, hind wings with both media and cubitus present. Forms living in the somewhat crumpled leaves of their host.

Type (fixed by Gerstaecker, 1859), *Aphis populi* Fab.

Genus NEOPROCIPHILUS Patch.

Plate XIII, A–F.

1912. *Neoprociphilus* Patch, Bul. Me. Agr. Expt. Sta., no. 202, p. 174.

The genus Neoprociphilus Patch is very close indeed to Prociphilus, the characters which separate it being the somewhat more oval or rounded sensoria and the fact that the sensoria are not ciliate. However, in some of the species of *Prociphilus*, particularly in the fall forms, somewhat oval sensoria are met with. It is retained doubtfully.

Characters.—Stem mother with five-segmented antennæ. Cornicles absent, large wax plates similar to those of Prociphilus present. Alate form with six-segmented antennæ which are armed with oval or subcircular nonciliate sensoria. Fore wings with the media simple, hind wings with both media and cubitus present. Sexes small, apterous, and beakless. Oviparous female developing only one egg.

Forms living free upon their host, the stem mother and following generations in company.

Type (monotypical), *Pemphigus attenuatus* O. S.

Genus PROCIPHILUS Koch.

Plate XIII, G–N.

1857. *Prociphilus* Koch, Die Pflanzenläuse, p. 279.
1857. *Stagonia* Koch, Die Pflanzenläuse, p. 284.
1875. *Holzneria* Lichtenstein, Bul. Soc. Ent. Fr. (5) v. 5, p. LXXVI.
1917. *Nishiyana* Matsumura, Synopsis of the Pemphigidae of Japan, p. 90.

In 1857 Koch erected his genus Prociphilus with three species: *bumeliae* Schrank, *erraticus* Koch, and *gnaphalii* Kalt. Later in the work (p. 284) he used *xylostei* De Geer as the type of the genus Stagonia. This species, *xylostei*, is in all respects similar to *bumeliae* and therefore Stagonia becomes a synonym of Prociphilus. In 1875 Lichtenstein erected the genus Holzneria with *poschingeri* Holzner as type. *Poschingeri* has been considered by many authors as the alternate form of *bumeliae*. In such case Holzneria must necessarily be a synonym of Prociphilus. Should *poschingeri*, however, be proven to be a distinct species it is so similar in all regards that Holzneria must remain a synonym.

In 1917 Matsumura erected the genus Nishiyana with *N. aomoriensis* Mats. as type, placing it close to Prociphilus. From this genus he separated it because of the absence of wax plates in the thorax and the somewhat shorter antennæ. It must be borne in mind, however, that the specimens he had were fall migrants. Fall migrants of several species of Prociphilus show very reduced wax plates, and in some these are absent altogether, although distinct in the spring migrants. It is believed that this genus is in reality Prociphilus.

Characters.—Cornicles absent, wax plates present, very large and well developed. Stem mother with five-segmented antennæ. Alate form with six-segmented antennæ armed with narrow transverse sensoria; secondary sensoria fringed. Fore wings with the media simple, hind wings with both media and cubitus present. Sexes small, apterous, and beakless. Oviparous females developing only one egg. Forms living in pseudogalls, the stem mother and her offspring together.

Type (fixed by Gerstaecker, 1859), *Aphis bumeliae* Schr.

Genus THECABIUS Koch.

Plate XIII, O–U.

1857. *Thecabius* Koch, Die Pflanzenläuse, p. 294.
1886. *Bucktonia* Lichtenstein, Monogr. d. pucerons, p. 16.

The genus Thecabius was erected by Koch in 1857 for his species *populneus*. This species proves to be a synonym of *Pemphigus affinis* Kalt. In 1886 Lichtenstein erected the genus Bucktonia with *affinis* Kalt. as type. Bucktonia, therefore, becomes a synonym.

Characters.—Cornicles absent; wax plates present but not prominently developed as in Prociphilus. Stem mother with five-segmented antennæ and rather narrow sensoria, secondary sensoria not fringed; fore wings with media simple, hind wings with both media and cubitus present. Sexual forms small, apterous, and beakless, oviparous female developing only one egg.

Forms living in galls, the stem mother usually living in a gall by herself.

Type (monotypical), *Thecabius populneus* Koch (=*Pemphigus affinis* Kalt.)

This genus is closely related to Prociphilus and it is with some hesitation that the writer places it as distinct. Certain species, such as *patchii* Gillette, which are undoubtedly congeneric with *affinis*, do not show the typical life habit of the stem mother living in a gall alone. However, the character of the sensoria and the undeveloped nature of the wax glands may serve to distinguish the genus.

Tribe FORDINI.

Members of the Fordini are specialized subterranean forms mostly living in the nests of ants. The aphids excrete honeydew, in return for which they are tended carefully by these insects. The apterous forms generally are of a yellowish or brownish-yellow color, sometimes a milk white. Wax-secreting plates are present but they are not developed to the same extent as are those of the Prociphilini. The cornicles are lost entirely and the region where these usually occur is occupied by wax plates. In some species the wax areas are reduced. Some species are armed with fine hairs, whereas others are almost entirely smooth. The eyes in the apterous forms are composed of three facets. The alate forms have rather short, thick antennæ with somewhat oval sensoria. Three genera compose the tribe and these may be separated as follows:

KEY TO THE GENERA OF THE FORDINI.

1. Antennæ of the alate form composed of five segments.....................Forda.
   Antennæ of the alate form composed of six segments..................... 2.
2. Sensoria of the antennæ of the alate form small and scattered over most of the segment, a central triangular wax plate on the thorax; apterous form with six-segmented antennæ..............................Paracletus.
   Sensoria of the antennæ of the alate form larger and more evenly placed; the sensoria sometimes extending evenly across the segment. Apterous form with five-segmented antennæ, sometimes with six segments present.....Geoica.

Genus FORDA Heyden

Plate XIII, V–AA.

1837. *Forda* Heyden, Mus. Sinkbg., v. 2, p. 291.
1841. *Rhizoterus* Hartig. Zeit. Ent., v. 3, p. 363.
1849. *Smynthurodes* Westwood, Gardener's Chron., p. 420.
1896. *Pentaphis* Horvath, Wien. Ent. Zeit., v. 15, p. 2.
1909. *Pentaphis* Del Guercio, Rivist. Patol. Vegetale, n. s., v. 3, p. 332.
1914. *Rectinasus* Theobald, The Entomologist, v. 47, p. 28.

In 1837 Heyden erected his genus Forda, the type of which is *formicaria* Heyden. In 1896 Horvath erected his genus Pentaphis with *marginata* Koch as a type, while Del Guercio in 1909 used *trivialis* Pass. as the type of a genus of the same name. Specimens of *marginata* Koch from Horvath prove that this species in every respect is similar to the type of the genus. Pentaphis, therefore, will become a synonym of Forda. Likewise specimens of *trivialis* show that this species belongs in the same genus. In 1841 Hartig erected the genus Rhizoterus, the type of which is *vacca*. According to Lichtenstein this species is a synonym of *formicaria* Heyden, and Rhizoterus also, then, becomes a synonym.

In 1914 Theobald erected his genus Rectinasus with his *buxtoni* as type. He based his genus on the proportions of the antennal segments, their length, and the length of the beak. The writer is opposed to basing genera on the proportions of the antennal segments, for in species in which these are of different proportions a very close relationship is evident. This is also true of the beak. Many American species taken in ants' nests and as yet undescribed have beaks ranging from small to longer than the body, but they are all evidently closely related. The other characters mentioned by Theobald are seen to be present in the type species. The tubercles he figures and describes are the same and the spines on the first and second antennal segments are evidently the thickened, pointed, chitinized articulations of the segments common in insects of this type. We believe, therefore, that Rectinasus should be carried as a synonym of *Forda*. Westwood's genus was erected on his *betae* which appears to belong here as recently indicated by the writer.

Characters.—Cornicles wanting; apterous forms with five-segmented antennæ and eyes of three facets. Alate form with five-segmented antennæ and medium-sized oval, or more or less irregularly shaped sensoria. Fore wings with media simple; hind wings with both media and cubitus present, arising slightly apart. Subterranean forms living usually in the nests of ants and tended by them.

Type (monotypical), *Forda formicaria* Heyden.

Genus GEOICA Hart.

Plate XIV, A–K.

1894. *Geoica* Hart, 18th Rept. State Ent. Ill., p. 101.
1860. *Tychea* Passerini, Gli Afidi, p. 30.
1906. *Tycheoides* Schouteden, Mem. Soc. Ent. Belg., v. 12, p. 194.
1906. *Kaltenbachiella* Schouteden, Mem. Soc. Ent. Belg., v. 12, p. 194.
1909. *Trifidaphis* Del Guercio, Rivista Patol. Vegetale, n. s., v. 3, p. 332.
1912. *Tullgrenia* V. d. Goot, Tijdschr. voor Ent., v. 15, p. 96.
1913. *Trinacriella* Del Guercio, Redia, v. 9, p. 169.
1916. *Serrataphis* V. d. Goot, Zur Kenntniss der Blattläuse Java's, p. 263.

In 1860 Passerini used the generic name Tychea of Koch and placed as the typical species *phaseoli* Pass. In 1863 he used the name again, listing several species but not the species included by Koch. Therefore his interpretation of the genus can not be correct. In 1894 Hart erected his genus Geoica with *squamosa* as type. In 1906 Schouteden noticed Passerini's mistake and suggested the name Tycheoides but made *eragrostidis* Pass. the type. In the same year he erected Kaltenbachiella with *menthae* Schout. as type. In the year 1909 Del Guercio erected Trifidaphis with *radicicola* Essig as type. In 1912 Van der Goot noted Passerini's mistake and proposed the name Tullgrenia for the Tychea of Passerini. In 1916 Van der Goot erected the genus Serrataphis with *lucifuga* Zehntner as type.

In studying cotypes and other specimens of *squamosa* certain generic characters are evident. The species is subterranean. It has five-segmented antennæ in the apterous form and six-segmented ones in the alate. It is true, however, that the apterous form sometimes has only four segments in the antennæ and the alate five. Indeed, in some alate forms there is a five-segmented antenna on one side and a six-segmented one on the other. One of these five-segmented antennæ was figured by Hart. One wing vein only was figured in the hind wing by Hart, but a very close examination shows that both the media and cubitus, though faint, are present. These are very difficult to trace in balsam mounts. In giving his name

Tycheoides Schouteden makes plain that he is naming the Tychea of Passerini and yet he sets a different type. He further states: "Le genre *Tychea* est vraisemblablement destiné à desparaître, ses espèces appartenant en réalité à *Tetraneura* ou *Byrsocrypta.*" He evidently is speaking here of the Tychea of Koch, since specimens of *Tychea* Pass. do not possess the cornicles of either of the two genera mentioned.

In describing Kaltenbachiella Schouteden gives as a character the four-segmented antennæ, etc., of the apterous form. The alate form he did not know, but from his description of the pupa it evidently would possess six-segmented antennæ. There seems little doubt that this is another such case as *squamosa* where the apterous form has often four-segmented antennæ, although five is the normal number, the alate form normally having six. Hart's description has led Schouteden astray and he places Geoica close to Forda, separating it therefrom by the venation of the hind wing. Considering all of these facts there seems little doubt that Kaltenbachiella should be placed as a synonym of Geoica.

Specimens of *phaseoli* show very similar characters in every respect. It is true that the antennæ are somewhat longer and the hairs simple, but in every respect of importance the insects agree. The apterous form has five-segmented antennæ and the alate form has six-segmented ones with the sensoria very similar in nature. The cauda also is very similar. It is evident then that Tychea Pass. and Tullgrenia V. d. Goot become synonyms of Geoica Hart. Specimens of *lucifuga* Zehntner show a remarkable resemblance to *squamosa* with the exception, of course, of the squamæ. The apterous form has five-segmented and the alate form six-segmented antennæ. In general form and structure of the caudal extremity the insects are the same and, therefore, Serrataphis V. d. Goot will become a synonym of Geoica. There remains, then, to discuss the genus Trifidaphis Del Guercio. The cotypes of the type species show a close resemblance to the general type of *squamosa*. The apterous forms have five-segmented antennæ and in the alate form, as in *squamosa*, some forms have five segments and some forms have six. The general resemblance in other respects seems to prove that Trifidaphis is a synonym of Geoica.

It should be pointed out that the sexes described by Hart are in all probability not sexual forms, but immature specimens.

In 1913 Del Guercio erected the genus Trinacriella for his new species *magnifica*. He gave a brief description stating that the apterous forms had five-segmented antennæ and the alate forms six. No specimens of this species are available to the writer, but there seems little doubt that Trinacriella will become a synonym of Geoica.

Characters.—Cornicles wanting; apterous form usually with five-segmented antennæ and eyes of three facets. With the intermediate forms more facets may occur. Alate form with usually six-segmented antennæ and rather large oval sensoria with distinct rims. Fore wings with media simple. Hind wings with both media and cubitus present, though these may be faint and almost obscured in balsam. Cauda large and somewhat rectangular or rounded. Subterranean forms living on the roots of plants. Sexes small, apterous, and beakless.

Type (monotypical), *Geoica squamosa* Hart.

Genus PARACLETUS Heyden.

Plate XIV, L–S.

1837. *Paracletus* Heyden, Mus. Sinkbg., v. 2, p. 295.

The genus Paracletus is closely related to Forda Heyden from which it may be distinguished by the number of antennal segments in both alate and apterous forms. As with other genera of this tribe the eyes of the apterous form consist of three facets. Intermediate forms often occur, however, in which the intermediate nature is indicated only by the eyes which have the beginnings of compound eyes, such as are found in the alate form. There never are, however, complete compound eyes. The genus was erected by Heyden in 1837. The species live in close association with ants.

Characters.—Cornicles absent. Apterous form with six-segmented antennæ and eyes of three facets; alate form with six-segmented antennæ which possess many rather small, oval sensoria. Fore wings with media simple, hind wings with both media and cubitus present, arising some distance apart. Thorax with a central wax plate. Forms living in the nest of ants and cared for by them. Sexes small, apterous, and beakless. In some cases only one claw is met with on the foot, while in other cases the normal number of two is present. This appears to be no definite character, as sometimes a claw is dropped from one foot and sometimes from another.

Type (monotypical), *Paracletus cimiciformis* Heyden.

Subfamily IV, HORMAPHIDINAE.

The genera placed in this subfamily have usually been placed with the Eriosomatinae, or Pemphiginae, as it has been sometimes called. Mordwilko, however, placed these forms as his third tribe under the subfamily Aphidinae next to his tribe Callipterea. Something can be said in favor of both of these placings. In the first instance, the species in general form, antennal structure, and habit of gall formation are no doubt suggestive of the Eriosomatinae. On the other hand, their structure in regard to cauda and anal plate is very like the Callipterina and the sexual forms appear to have a development of their own, although they are nearer in many ways to the Aphidinae than to the Eriosomatinae.

It is the author's belief that these forms should constitute a separate subfamily. It has developed the habit of gall formation and the sensory characters which usually accompany it, while at the same time it has retained in the sexual female the normal development of the ovaries found in the more primitive groups, and has retained in both sexual forms the beak and the ability to feed. This at once suggests a different line of development from that taken by the Eriosomatinae, although in some of its habits the Hormaphidinae agrees with that subfamily. In other lines, however, marked differences are met with here and one of the most striking of these is development of aleyrodiform generations, which remain stationary upon the host. Such a development is never met with in the Eriosomatinae, although the sexual forms are much more specialized.

Since many of the genera of the Hormaphidinae are gall formers, sensoria very similar to those met with in the Eriosomatinae are met with here also. Indeed the same annular sensoria found in the Eriosomatini are even more pronounced in the Hormaphidinae and the sensoria on the wing bases are prominent and often, numerous.

The cornicles in the present subfamily are sometimes absent or, as is usually the case, reduced to mere rings. In some genera, however, they may be elevated slightly on broad shallow cones, somewhat suggestive of those of Anoecia. No prominent cornicles, however, occur.

In the wing venation there is often a considerable reduction and this shows also the specialized nature of the insects. The venation is comparable to that met with in the Eriosomatinae. In the fore wings the media is either simple or once branched, the radial sector, cubitus, and anal are present, but the cubitus and anal are often fused near their bases. In the hind wings both the media and cubitus are sometimes present, but often only the media remains.

Great specialization in wax-producing organs occurs. In many of the forms these agree with the ones found in the Pemphigini. In certain aleyrodiform generations and in some sexual forms agglomerate glands or rather groups of small glands are seen. These may be arranged in different ways and often are placed about the margin of the insect so that it possesses a distinct lateral fringe, very like that of an aleyrodid. In fact some of these insects on this account are very often mistaken for aleyrodids.

The sexual forms are often quite small and possess large wax-producing areas. Others may lack these. All, however, develop to normal adults.

The habit of gall formation is very marked here. Indeed, some species form galls on two different species of plants, migrating between the two.

Characters.—Aerial forms living in galls or sometimes free upon the host. The mesothorax in many forms altered so that its divisions are more or less unobservable, the entire mesothorax often showing as only one plate. Scalelike or aleyrodiform generations often developed. Cornicles often reduced to mere ringlike openings or entirely absent. Sexual forms small and apterous but with fully developed beaks. Oviparous female laying several eggs.

KEY TO THE TRIBES OF THE HORMAPHIDINAE.

1. Aleyrodiform generations developed.. 2.
   Aleyrodiform generations not developed..............................OREGMINI.
2. Cornicles absent; insects usually gall formers....................HORMAPHIDINI.
   Cornicles usually present; insects usually not gall formers.......CERATAPHIDINI.

Tribe HORMAPHIDINI.

Members of this tribe are distinguished easily from those of other tribes in that the cornicles are absent and aleyrodiform generations are developed. These remain more or less quiescent upon the foliage. Some different forms of the species are often gall producers. All secrete wax from special pores. Considerable variation is met with in the development of the aleyrodiform generations. Sensoria of the alate forms are usually narrow and annular.

Only two genera are so far recorded.

KEY TO THE GENERA OF THE HORMAPHIDINI.

Antennæ of the alate forms composed of three segments, hind wings with only the media present..Hormaphis.
Antennæ of the alate forms composed of five segments, hind wings with both media and cubitus present.......................................Hamamelistes.

Genus HAMAMELISTES Shimer.

Plate XIV, T-X.

1867. *Hamamelistes* Shimer, Trans. Am. Ent. Soc., v. 1, p. 284.
1896. *Tetraphis* Horvath, Wien. Ent. Zeit., v. 15, p. 6.

Shimer included two species in this genus, *spinosus* Shimer and *cornu* Shimer. The latter species, as suspected by him, is a synonym of *hamamelidis* Fitch. This species has been made the type of Hormaphis.

Characters.—Cornicles absent. Stem mother with four-segmented antennæ. Aleyrodiform generations developed. Alate form with five-segmented antennæ which are armed with numerous annular sensoria. Wings held flat in repose; fore wings with the media simple; hind wings with both media and cubitus usually present; cauda knobbed, anal plate bilobed; wax-secreting areas abundantly present in the apterous forms. Sexes small and apterous but with beaks developed, oviparous female laying several eggs.

Forms living in galls upon the leaves or scale-like on the leaves or twigs.

Type (one unquestioned species), *Hamamelistes spinosus* Shimer.

Genus HORMAPHIS Osten-Sacken.

Plate XIV, Y-FF.

1861. *Hormaphis* Osten-Sacken, Stettiner Ent. Zeit., p. 422.

The genus Hormaphis was erected by Osten Sacken for a species he described as *hamamelidis*. This species it later proved was the same described by Fitch as *Byrsocrypta hamamelidis*. The genus later was made to include *spinosus* Shimer, but the distinction between this genus and the one described by Shimer has been pointed out by Pergande.[1]

Characters.—Cornicles absent; aleyrodiform generations developed; wax glands very numerous; stem mother with three-segmented antennæ; alate forms with three-segmented antennæ which are armed with distinct annular sensoria. Wings held flat in repose; fore wings with the media simple; hind wings with the cubitus absent. Sexual forms small and apterous, possessing beaks, oviparous female laying several eggs.

Type (monotypical), *Hormaphis hamamelidis* O. S. (*Byrsocrypta hamamelidis* Fitch).

Tribe OREGMINI.

Characters.—Forms living in galls or otherwise upon the leaves of plants, possessing cornicles and wax secreting glands. Antennæ of the winged forms usually armed with annular sensoria; cauda rounded or somewhat knobbed, anal plate somewhat bilobed. No aleyrodiform generations developed. The sexual forms appear to be unknown.

KEY TO THE GENERA OF THE OREGMINI.

1.	Vertex with two horn-like projections	2.
	Vertex without such horn-like projections	3.
2.	Antennæ five-segmented	Oregma.
	Antennæ four-segmented	Ceratoglyphina.
3.	Antennæ of apterous form with five segments	4.
	Antennæ of apterous form with four segments	Glyphinaphis.
4.	Media of fore wings once branched	Astegopteryx.
	Media of fore wings simple	Mansakia.

Genus ASTEGOPTERYX Karsch.

Plate XV, Q-X.

1890. *Astegopteryx* Karsch, Ber. deutsch Botan. Ges., v. 8, p. 52.
1906. *Nipponaphis* Pergande, Ent. News, v. 17, p. 205.
1916. *Schizoneuraphis* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 245.

The genus Astegopteryx was erected with *styracophila* Karsch as type. Another species, *nekoashi*, was described by Sasaki before the International Congress at Brussels in 1911 and a third species, *styraci*, was described by Matsumura in 1917. It is possible, therefore, to gain a fair conception of the characters. In 1906 Pergande erected his genus Nipponaphis with *distychii* Perg. as type. This species was stated to be from *Distychium racemosum* in Japan, on

[1] Pergande, T. The life history of two species of plant lice inhabiting both the witch-hazel and birch. U. S. Dept. Agr. Bur. Ent. Tech. Ser. no. 9. 1901.

which it forms galls. In 1916 Van der Goot erected his Schizoneuraphis with *gallorum* V. d. Goot as type. This species was said to form galls on *Distylium stellare.*

The genus Astegopteryx can be separated as far as the recognized forms are concerned by the proportion of the antennal segments and some variation in the shape of the stigma. These differences are not, however, of large importance and Nipponaphis should be a synonym of Astegopteryx. In the same way, the type of Van der Goot's genus is not sufficiently different to warrant the erection of a new genus and Schizoneuraphis also should be considered a synonym.

Characters.—Cornicles broad rings; apterous form with five-segmented antennæ; alate form with five-segmented antennæ which are armed with annular sensoria. fore wings with the media once branched; hind wings with both media and cubitus present. Stigmal vein arising rather far back on the stigma. Cauda rounded, anal plate somewhat bilobed; forms living in galls.

Sexual forms unknown.

Type (monotypical), *Astegopteryx styracophila* Karsch.

Genus CERATOGLYPHINA Van der Goot.

Plate XV, M–P.

1916. *Ceratoglyphina* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 237.

Characters.—Cornicles present as mere pores. Vertex with two hornlike projections. Antennæ of four segments; cauda and anal plate both rounded. Winged orms unknown.

Type (fixed by V. d. Goot, 1916), *Ceratoglyphina bambusae* V. d. Goot.

Genus GLYPHINAPHIS Van der Goot.

Plate XV, H–K.

1916. *Glyphinaphis* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 232.

Characters.—Cornicles present as mere pores; antennæ of four segments which are armed with linear sensoria. Fore wings with the media once branched; hind wings with both media and cubitus present; cauda knobbed; anal plate rounded; body covered with stout hairs.

Type (fixed by V. d. Goot, 1916), *Glyphinaphis bambusae* V. d. Goot.

Genus MANSAKIA Matsumura.

Plate XV, L.

1917. *Mansakia* Matsumura, Synopsis of the Pemphigidae of Japan, p. 59.

The author of the genus Mansakia stated that it is closely allied to Hormaphis, but it would appear to the writer to be related to the genera in the Oregmini as understood in the present classification. The presence of the cornicles would indicate that the genus is not related as closely to Hormaphis as to Astegopteryx, but its host and the nature of the gall would place it close to Hamamelistes. Since all of the forms are not known it is impossible to state positively its position.

Characters.—Cornicles present as mere rings. Antennæ of five segments armed with annular sensoria. Fore wings with the media simple, hind wings with two oblique veins. Cauda rounded, anal plate somewhat bilobed. Sexes not known.

Forms causing galls upon plants, the galls usually armed with numerous long projections.

Type (fixed by Matsumura, 1917), *Mansakia miyabei* Mats.

Genus OREGMA Buckton.

Plate XV, A-G.

1893. *Oregma* Buckton, Ind. Mus. Notes, v. 3, p. 87.
1897. *Ceratovacuna* Zehntner, Mededl. Proefs. Java, n. s., no. 37, p. 29.

In 1893 Buckton established his genus Oregma with *bambusae* Buckton as type, while in 1897 Zehntner established his Ceratovacuna with *lanigera* Zehntner as type. Specimens of both of these species sent by Zehntner and specimens of *bambusae* from Green taken in Ceylon show that these genera must be considered the same.

Characters.—Both alate and apterous forms with two hornlike projections on the vertex, wax gland areas present; antennæ five-segmented, those of the alate form with narrow annular sensoria; cauda rounded or somewhat knobbed; fore wings with media twice forked, hind wings with both media and cubitus present; cornicles broad, slightly elevated rings.

Type (monotypical), *Oregma bambusae* Buckt.

Tribe CERATAPHIDINI.

This tribe is closely related to the Hormaphidini but differs in that very distinct cornicles are here present. The apterous forms are scalelike and quiescent and feed upon the surfaces of the leaves. The alate forms possess annular sensoria. Wax secretion is abundant.

The genera may be separated as follows:

KEY TO THE GENERA OF THE CERATAPHIDINI.

Antennæ of the aleyrodiform generations of five segments .... Aleurodaphis.
Antennæ of the aleyrodiform generations of four segments .... Cerataphis.
Antennæ of aleyrodiform generations of three segments .... Thoracaphis.

Genus ALEURODAPHIS Van der Goot.

Plate XVI, A-E.

1916. *Aleurodaphis* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 239.

This genus was erected for one species occurring in Java.

Characters.—Form flat, aleyrodiform, three distinct divisions evident; cornicles present as mere rings. Margin with wax secreting glands; dorsum also with many small glands. Cauda rather elongate and knobbed, anal plate bilobed. Antennæ five-segmented; eyes of the apterous forms with three facets.

Type (fixed by Van der Goot, 1916), *Aleurodaphis blumeae* V. d. Goot.

Genus CERATAPHIS Lichtenstein.

Plate XVI, F–M.

1862. *Boisduvalia* Signoret, Ann. Ent. Soc. France (4), v. 8, p. 400.
1882. *Cerataphis* Lichtenstein, Bul. Ent. Soc. France (6), v. 2, p. xvi.

Signoret erected his genus Boisduvalia in connection with his aleyrodid monograph. He placed *Coccus lataniae* Bois. as type. Later, however, he considered this a coccid genus. The name was used in the Diptera in 1830, and is therefore not available. The name Cerataphis used by Lichtenstein in 1882 appears as the next name applied to the genus.

Characters.—Cornicles present as mere rings. Apterous form with four-segmented antennæ and aleyrodiform, with two divisions to the body; wax glands prominent; vertex with two hornlike projections; alate form with five-segmented antennæ, the segments armed with narrow annular sensoria. Fore wings with the media once branched, hind wings with both media and cubitus present. Cauda knobbed; anal plate bilobed.

Type (monotypical), *Coccus lataniae* Bois.

Genus THORACAPHIS Van der Goot

Plate XVI, N–W.

1916. *Thoracaphis* Van der Goot, Zur Kenntniss der Blattläuse Java's, p. 242.

Only the apterous form of one species of this genus has been described. Other species, however, are available for study, through the generosity of Professor Van der Goot.

Characters.—Cornicles present and quite distinct, occasionally absent, however, in the apterous form. Apterous form with three-segmented antennæ, flat and with a posterior lobe. Alate form with five-segmented antennæ armed with annular sensoria. Fore wings with the media once branched; hind wings with both media and cubitus present. Cauda somewhat knobbed, anal plate bilobed.

Type (monotypical), *Thoracaphis arboris* V. d. Goot.

GENERA NOT PLACED.

A number of genera have been described which the writer has been unable to place. These genera are discussed in the following notes.

Genus RHIZOBIUS Burmeister.

1835. *Rhizobius* Burmeister, Handbuch der Entomologie, p. 78.
1849. *Rhizophthiridum* Van der Hoeven, Handb. Dierkunde v. 1, p. 508.
1860. *Rhyzoicus* Passerini, Gli Afidi, p. 30.
1863. *Rizobius* Passerini, Aphididae Italicae, p. 79.
1919. *Rhizoicus* Del Guercio, Redia, v. 12, p. 251.

The genus Rhizobius has generally been considered as a good aphid genus and writers have referred to species in this genus as having but one claw to the tarsus. However, as indicated under Paracletus the writer believes this is a variable character and we have no definite knowledge in regard to *pilosellae* Burm. Buckton's species of course was not in the original genus and therefore can not be used as type nor was it in Passerini's conception of Rhyzoicus. After placing Rhyzoicus Pass. with *jujubae* Buckton as type, Del Guercio erects the genus Neorhizobius, distinguished by having two claws, and in which he places *graminis* Thos., *poae* Del Guercio, *stramineus* Del Guercio, and *ulmiphilus* Del Guercio.

In 1860 Passerini set *sonchi* Pass. as the type of Rhizobius Burm., and in a footnote suggested the name Rhyzoicus as a new name for Rhizobius, since this name had previously been used in the Coleoptera. Such procedure, however, is not allowable since *sonchi* Pass. was not in the original genus. Of the two species in the original genus *pilosellae* Burm. has been accepted as type.

Del Guercio in 1917 used the generic name Rhizoicus Pass., spelling it with an "i" instead of a "y", and *jujubae* Buckton as the type.

In the writer's opinion the genus Rhizobius must remain unknown until the type species *pilosellae* becomes known and carefully studied.

The name Rhizophthiridum was given to this genus to replace Rhizobius Burm.

Genus NEORHIZOBIUS Del Guercio.

1917. *Neorhizobius* Del Guercio, Redia, v. 12, p. 251.

As indicated under the discussion of Rhizobius, four species are placed in this genus by Del Guercio. Three species are described as new and only in the apterous forms.

Two of these forms have five-segmented antennæ and one of them four-segmented ones, and when the alate forms are found they will in all probability be shown to represent species either of Forda or Geoica. The basing of genera upon the relative lengths of the antennal segments would create a very large number of genera and separate related forms. The genus Neorhizobius, therefore, the writer considers composed of apterous forms, which really belong in older and well-recognized genera, but which can not be definitely placed until the alate forms have been secured and studied.

Genus SCHOUTEDENIA Rübsaamen.

1905. *Schoutedenia* Rübsaamen, Marcellia, v. 4, p. 19.

This genus, which was described for *ralumensis* Rüb., is here listed as unknown. The gall formed by the species is described but the writer, never having been able to obtain either gall or insect, would be able only to guess at its position from the description.

Genus CLAVIGERUS Szépligeti.

Clavigerus Szépligeti, Rovarászati Lapok, v. 1, p. 4.

This genus was described in the only volume issued of the Journal cited. The writer has been unable to secure a copy or any details of the description given.

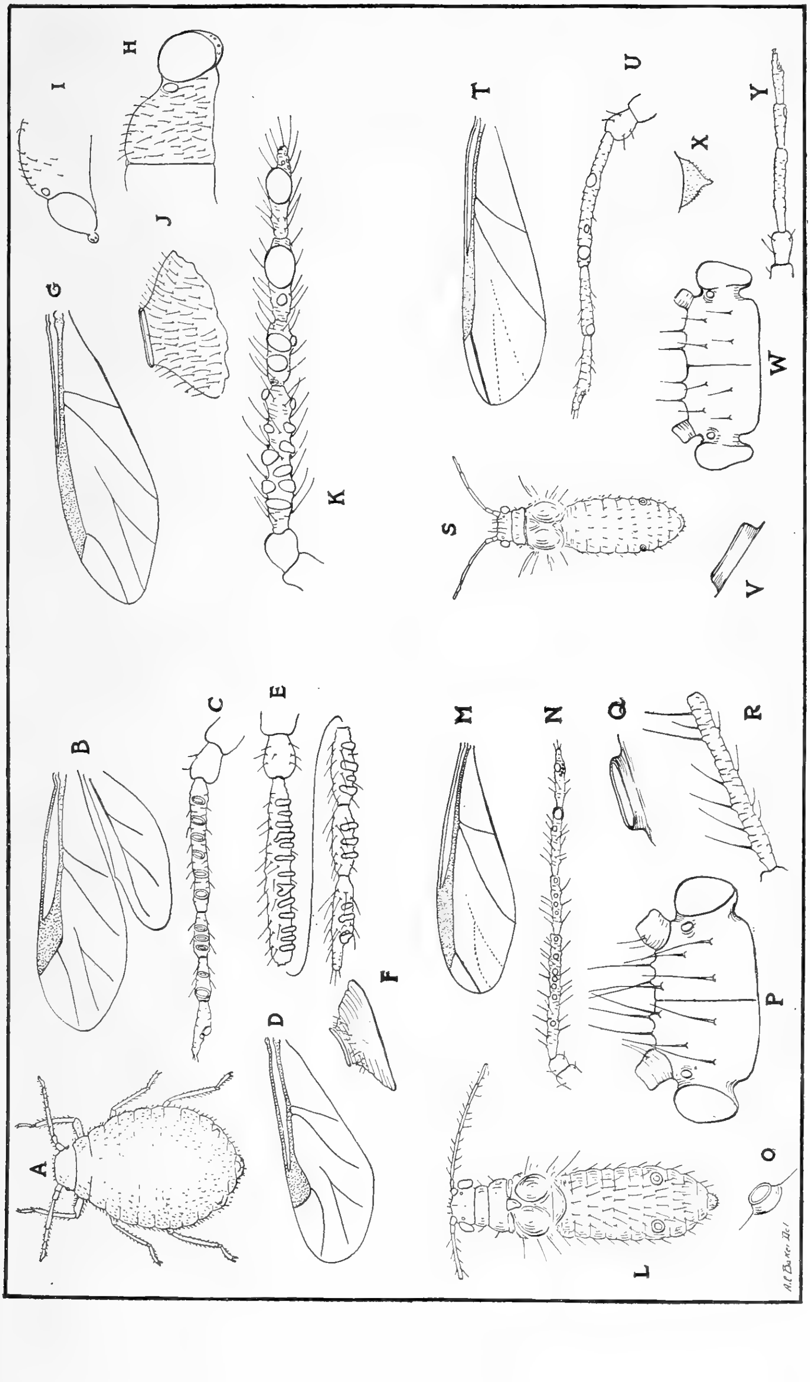
ADDENDA.

The following generic names have been employed by Mordwilko (Fauna Russ. vol. 1, Aphidodea) without, apparently, the mention of any species in connection therewith. They have not been considered in the foregoing paper: Anameson, Aorison, Chaetosiphon, Corylobium, Elatobium, Euaulax, Eurythaphis, Halmodaphis, Impatientinum, Jaxartaphis, Nasonovia, Orobion, Paczoskia, Sitobium, Staticobium, Tlja, Turanaphis, Uroleucon (subgenus), Uromelan. The subgenera Dactynotus Raf., Cladoxus Raf., and Adactynus Raf., have not been considered.

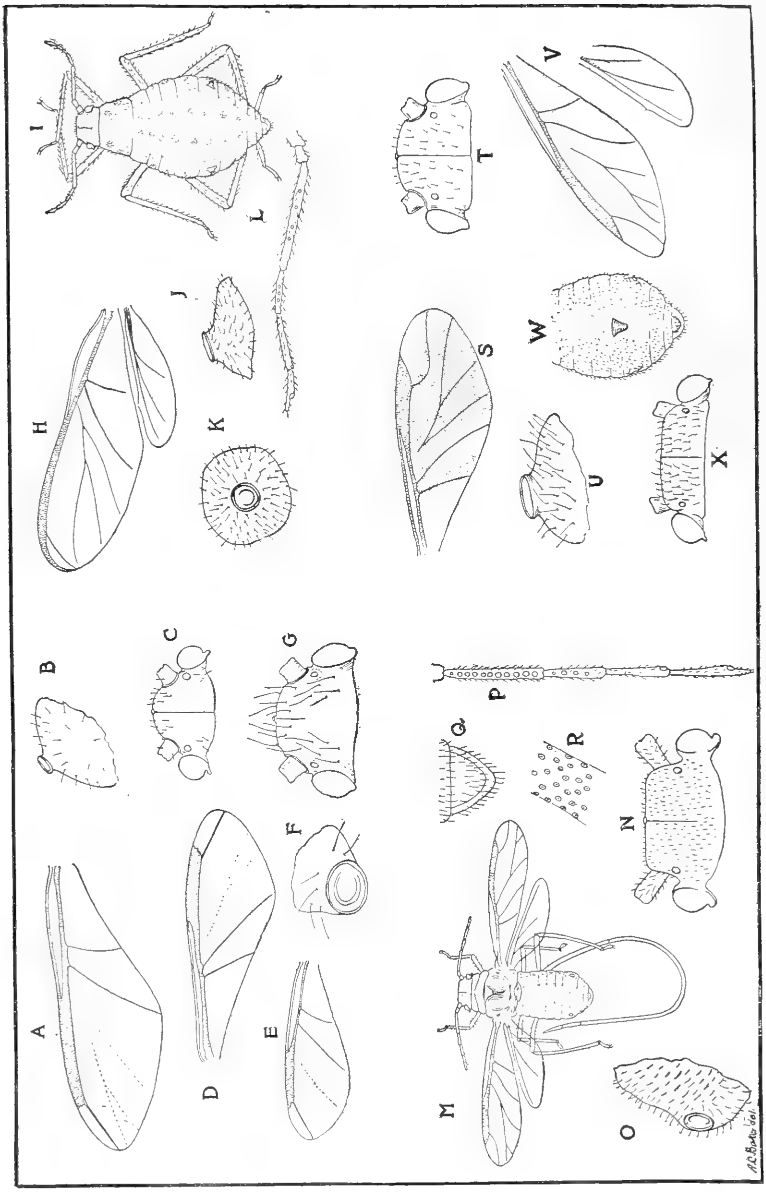
INDEX TO GENERA.

PLATE I.

A.—*Anoecia querci*, apterous form.
B.—*Anoecia querci*, wings.
C.—*Anoecia querci*, antenna of alate form.
D.—*Anoecia corni*, fore wing.
E.—*Anoecia corni*, antenna of alate form.
F.—*Anoecia corni*, cornicle of alate form.
G.—*Nippolachnus pyri*, fore wing.
H.—*Nippolachnus pyri*, head of alate form.
I.—*Anoecia corni*, head of alate form.
J.—*Nippolachnus pyri*, cornicle of alate form.
K.—*Nippolachnus pyri*, antenna of alate form.
L.—*Eulachnus agilis*, body of alate form.
M.—*Eulachnus agilis*, fore wing.
N.—*Eulachnus agilis*, antenna of alate form.
O.—*Eulachnus agilis*, cornicle of alate form.
P.—*Eulachnus rileyi*, head of alate form.
Q.—*Eulachnus rileyi*, cornicle of alate form.
R.—*Eulachnus rileyi*, segment III, antenna of alate form.
S.—*Essigella californica*, body of alate form.
T.—*Essigella californica*, fore wing.
U.—*Essigella californica*, antenna of alate form.
V.—*Essigella californica*, cornicle of alate form.
W.—*Essigella californica*, head of alate form.
X.—*Essigella californica*, cauda of alate form.
Y.—*Essigella californica*, antenna of apterous form



GENERIC CLASSIFICATION OF APHIDIDAE.



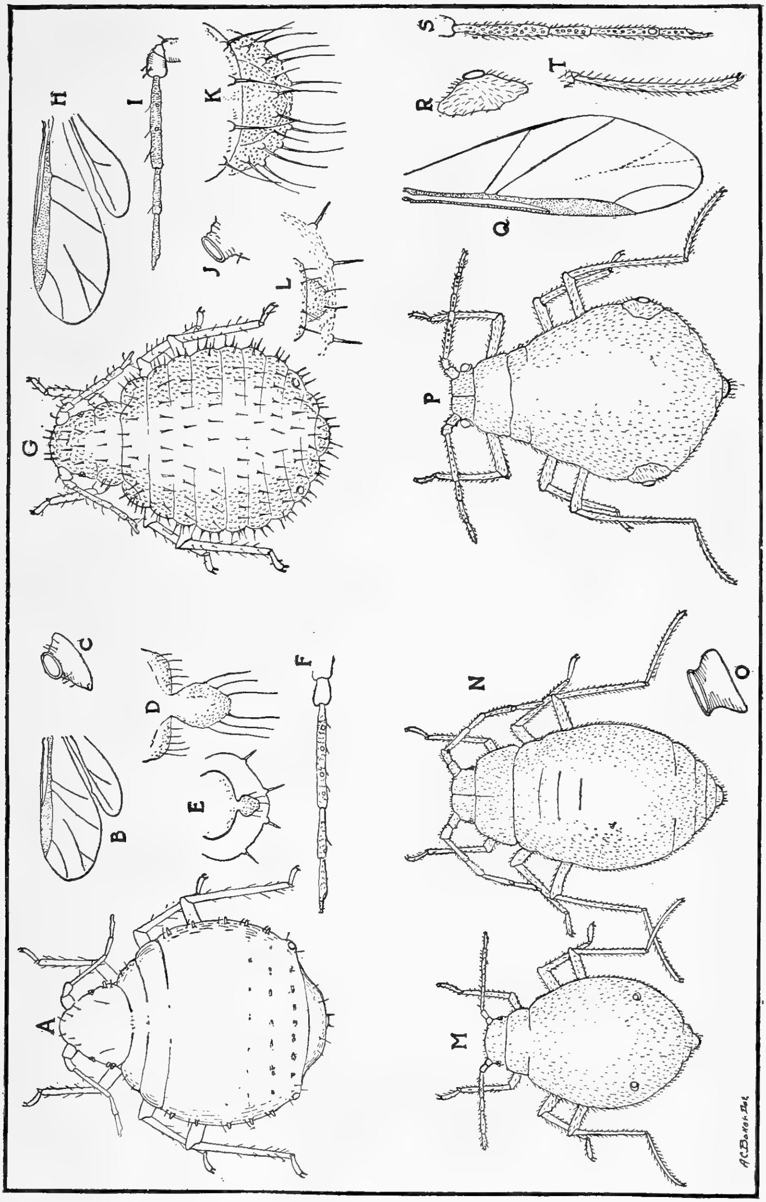
GENERIC CLASSIFICATION OF APHIDIDAE.

PLATE II.

A.—*Dilachnus ponderosae*, fore wing.
B.—*Dilachnus ponderosae*, cornicle of apterous form.
C.—*Dilachnus ponderosae*, head of alate form.
D.—*Schizolachnus tomentosus*, fore wing.
E.—*Unilachnus parvus*, fore wing.
F.—*Unilachnus parvus*, cornicle of alate form.
G.—*Unilachnus parvus*, head of alate form.
H.—*Longistigma caryae*, wings.
I.—*Longistigma caryae*, apterous form.
J.—*Longistigma caryae*, cornicle.
K.—*Longistigma caryae*, cornicle.
L.—*Longistigma caryae*, antenna of alate form.
M.—*Stomaphis quercus*, alate form.
N.—*Stomaphis quercus*, head of alate form.
O.—*Stomaphis quercus*, cornicle of alate form.
P.—*Stomaphis quercus*, antenna of alate form.
Q.—*Stomaphis quercus*, cauda and anal plate.
R.—*Stomaphis quercus*, pits on rostrum.
S.—*Pterochlorus roboris*, wing.
T.—*Pterochlorus roboris*, head of alate form.
U.—*Pterochlorus roboris*, cornicle of alate form.
V.—*Pterochlorus viminalis*, wings.
W.—*Pterochlorus viminalis*, abdomen of alate form.
X.—*Pterochlorus viminalis*, head of alate form.

PLATE III.

A.—*Thelaxes dryophila*, apterous form.
B.—*Thelaxes dryophila*, wings.
C.—*Thelaxes dryophila*, cornicle of alate form.
D.—*Thelaxes dryophila*, cauda of alate form.
E.—*Thelaxes dryophila*, cauda of apterous form.
F.—*Thelaxes dryophila*, antenna of alate form.
G.—*Glyphina betulae*, apterous form.
H.—*Glyphina betulae*, wings.
I.—*Glyphina betulae*, antenna of alate form.
J.—*Glyphina betulae*, cornicle of alate form.
K.—*Glyphina betulae*, cauda and anal plate of alate form.
L.—*Glyphina betulae*, cauda and anal plate of apterous form.
M.—*Neotrama delguercioi*, apterous form.
N.—*Trama troglodytes*, apterous form.
O.—*Neotrama delguercioi*, cornicle.
P.—*Protrama radicis*, apterous form.
Q.—*Protrama radicis*, fore wing.
R.—*Protrama radicis*, cornicle of alate form.
S.—*Protrama radicis*, antenna of alate form.
T.—*Protrama radicis*, tarsus of alate form.



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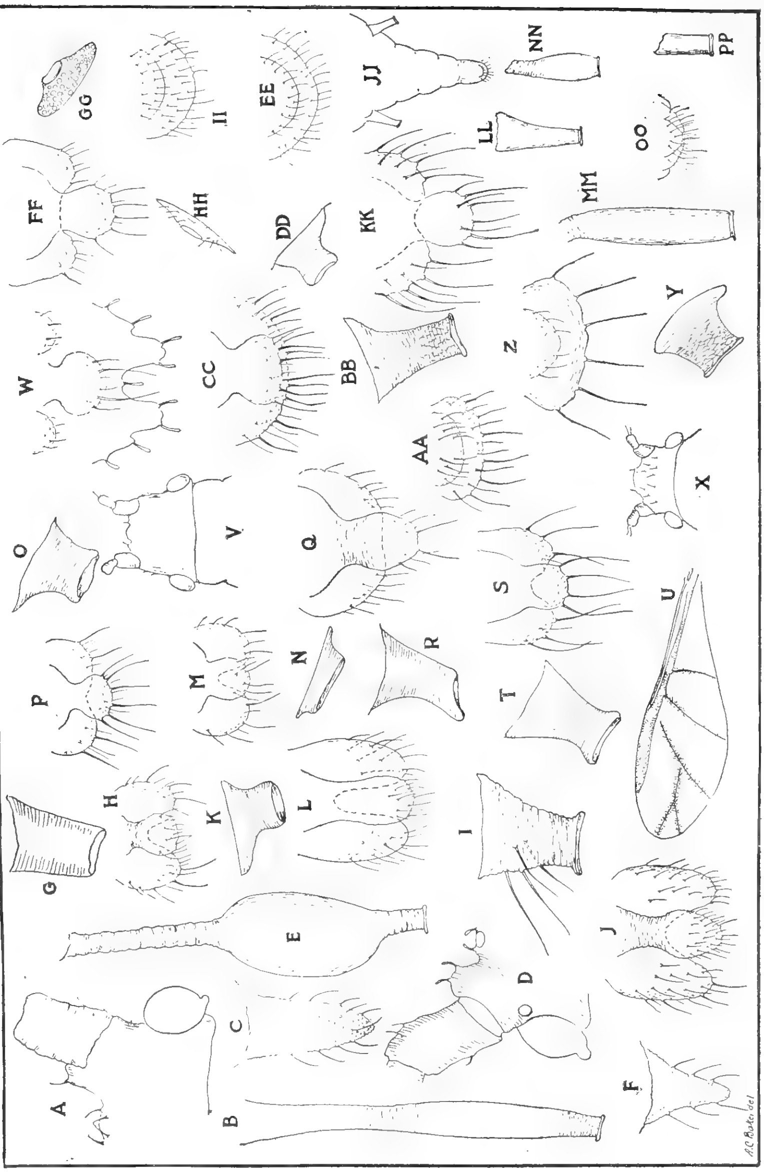


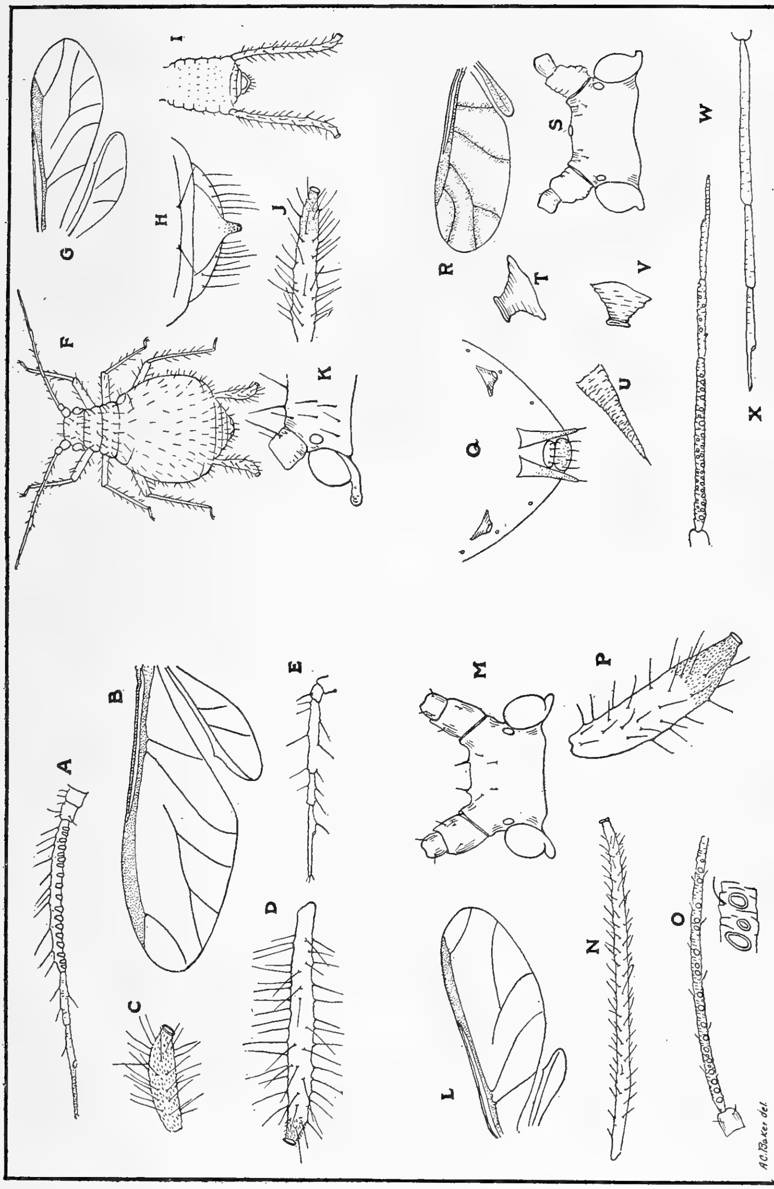
GENERIC CLASSIFICATION OF APHIDIDAE.

PLATE IV.

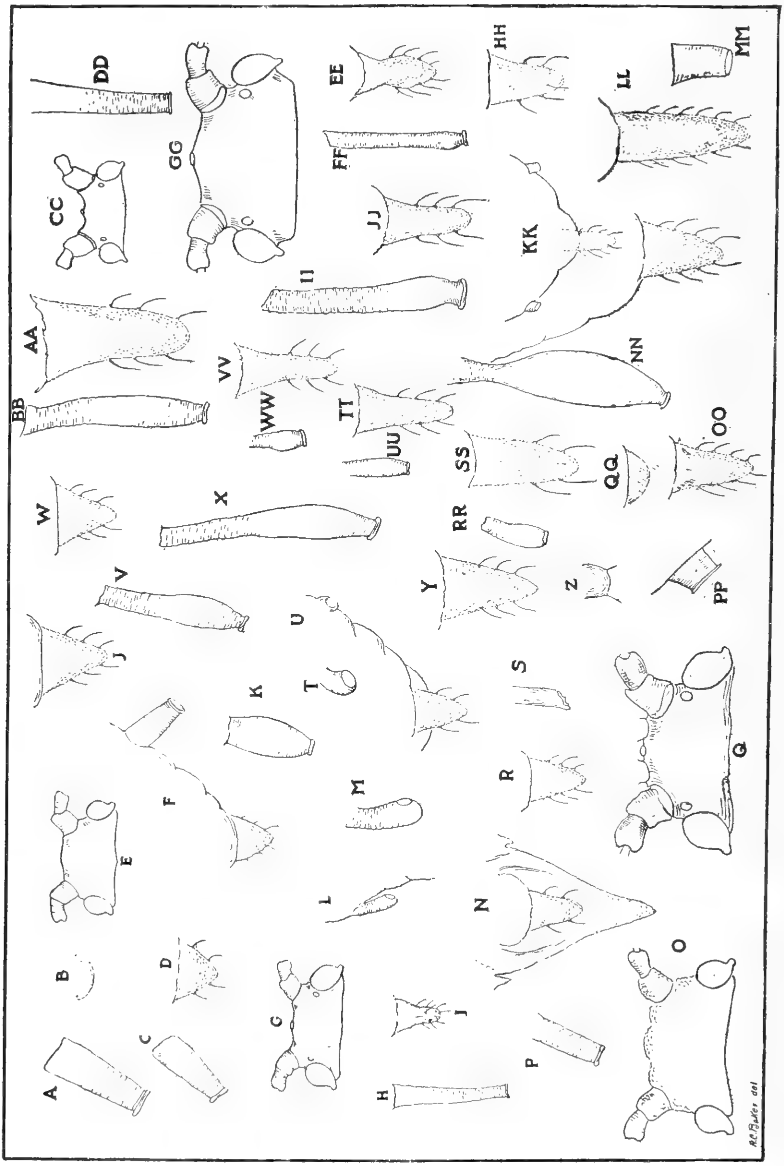
A.—*Amphorophora rubi*, head of apterous form.
B.—*Amphorophora rubi*, cornicle.
C.—*Amphorophora rubi*, cauda.
D.—*Rhopalosiphoninus latysiphon*, head of alate form.
E.—*Rhopalosiphoninus latysiphon*, cornicle of alate form.
F.—*Rhopalosiphoninus latysiphon*, cauda of alate form.
G.—*Myzocallis coryli*, cornicle.
H.—*Myzocallis coryli*, cauda and anal plate.
I.—*Callipterus juglandis*, cornicle.
J.—*Callipterus juglandis*, cauda and anal plate.
K.—*Therioaphis tiliae*, cornicle.
L.—*Therioaphis tiliae*, cauda and anal plate.
M.—*Monellia caryella*, cauda and anal plate.
N.—*Monellia caryella*, cornicle.
O.—*Chromaphis juglandicola*, cornicle.
P.—*Chromaphis juglandicola*, cauda and anal plate.
Q.—*Euceraphis betulae*, cauda and anal plate.
R.—*Euceraphis betulae*, cornicle.
S.—*Calaphis betulella*, cauda and anal plate.
T.—*Calaphis betulella*, cornicle.
U.—*Calaphis betulella*, fore wing.
V.—*Saltusaphis scirpus*, head of apterous form.
W.—*Saltusaphis scirpus*, cauda and anal plate.
X.—*Thripsaphis balli*, head of apterous form.
Y.—*Neothomasia populicola*, cornicle.
Z.—*Neothomasia populicola*, cauda and anal plate.
AA.—*Periphyllus negundinis*, cauda and anal plate.
BB.—*Periphyllus negundinis*, cornicle.
CC.—*Chaitophorus populi*, cauda and anal plate.
DD.—*Symydobius oblongus*, cornicle.
EE.—*Symydobius oblongus*, cauda and anal plate.
FF.—*Phyllaphis fagi*, cauda and anal plate.
GG.—*Phyllaphis fagi*, cornicle.
HH.—*Tamalea coweni*, cornicle.
II.—*Tamalea coweni*, cauda and anal plate.
JJ.—*Drepanaphis acerifolii*, oviparous abdomen.
KK.—*Drepanaphis acerifolii*, cauda and anal plate of alate form.
LL.—*Drepanaphis acerifolii*, cornicle.
MM.—*Drepanosiphum platanoides*, cornicle.
NN.—*Melanoxantherium populifoliae*, cornicle.
OO.—*Melanoxantherium populifoliae*, cauda and anal plate.
PP.—*Pterocomma populeus*, cornicle.

PLATE V.

A.—*Eutrichosiphum pasaniae*, antenna of alate form.
B.—*Eutrichosiphum pasaniae*, wings.
C.—*Eutrichosiphum pasaniae*, cornicle of apterous form.
D.—*Eutrochosiphum pasaniae*, cornicle of alate form.
E.—*Eutrichosiphum pasaniae*, antenna of apterous form.
F.—*Greenidea anonae*, apterous form.
G.—*Greenidea artocarpi*, wings.
H.—*Greenidea artocarpi*, cauda of apterous form.
I.—*Greenidea artocarpi*, cornicle of apterous form.
J.—*Greenidea anonae*, abdomen of alate form.
K.—*Greenidea anonae*, head of alate form.
L.—*Greenideoida elongata*, wings.
M.—*Greenideoida* sp., head of alate form.
N.—*Greenideoida* sp., cornicle of alate form.
O.—*Greenideoida* sp., third antennal segment of alate form.
P.—*Greenideoida hannae*, cornicle of apterous form.
Q.—*Setaphis luteus*, caudal portion of apterous form.
R.—*Setaphis luteus*, wings.
S.—*Setaphis luteus*, head of alate form.
T.—*Setaphis luteus*, cornicle of alate form.
U.—*Setaphis luteus*, spine of alate form.
V.—*Setaphis luteus*, cornicle of apterous form.
W.—*Setaphis luteus*, antenna of alate form.
X.—*Setaphis luteus*, antenna of apterous form.



GENERIC CLASSIFICATION OF APHIDIDAE.



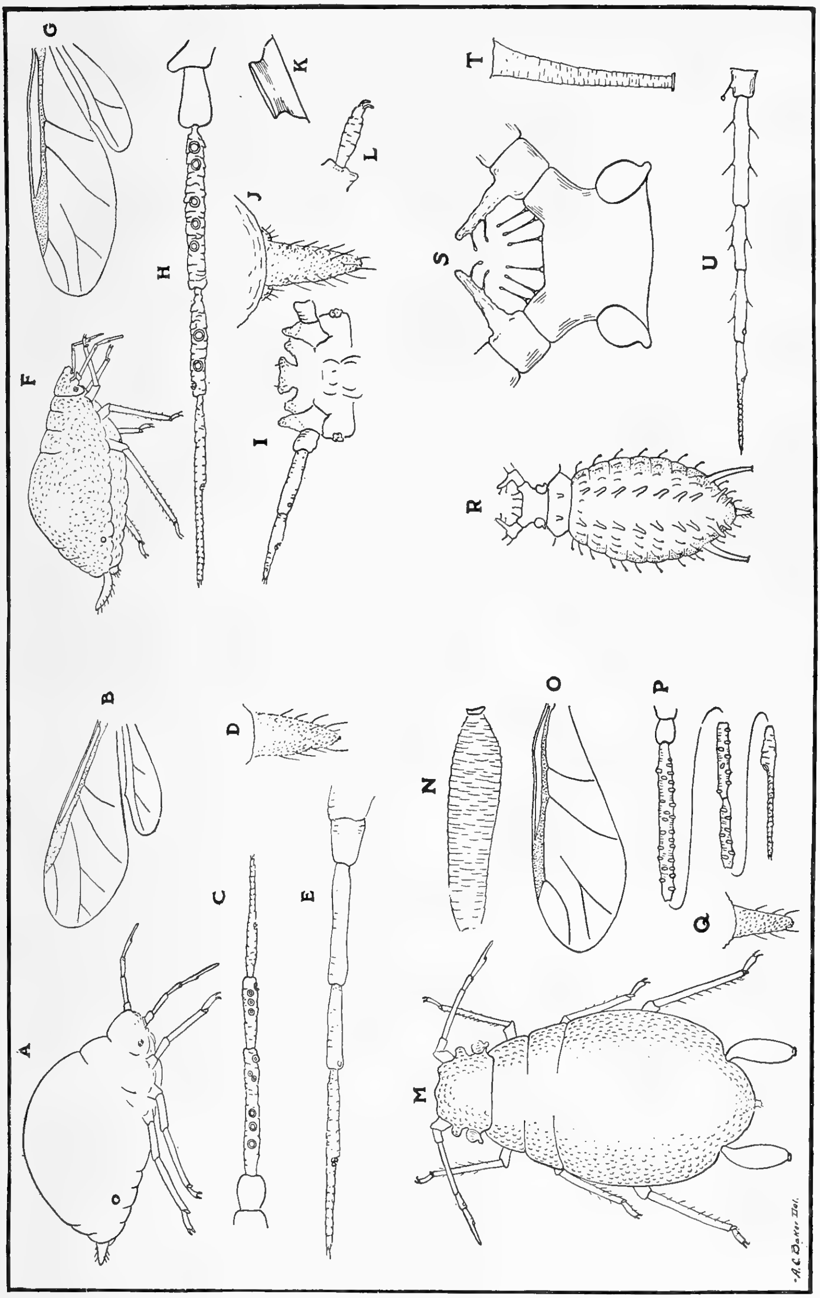
GENERIC CLASSIFICATION OF APHIDIDAE.

PLATE VI.

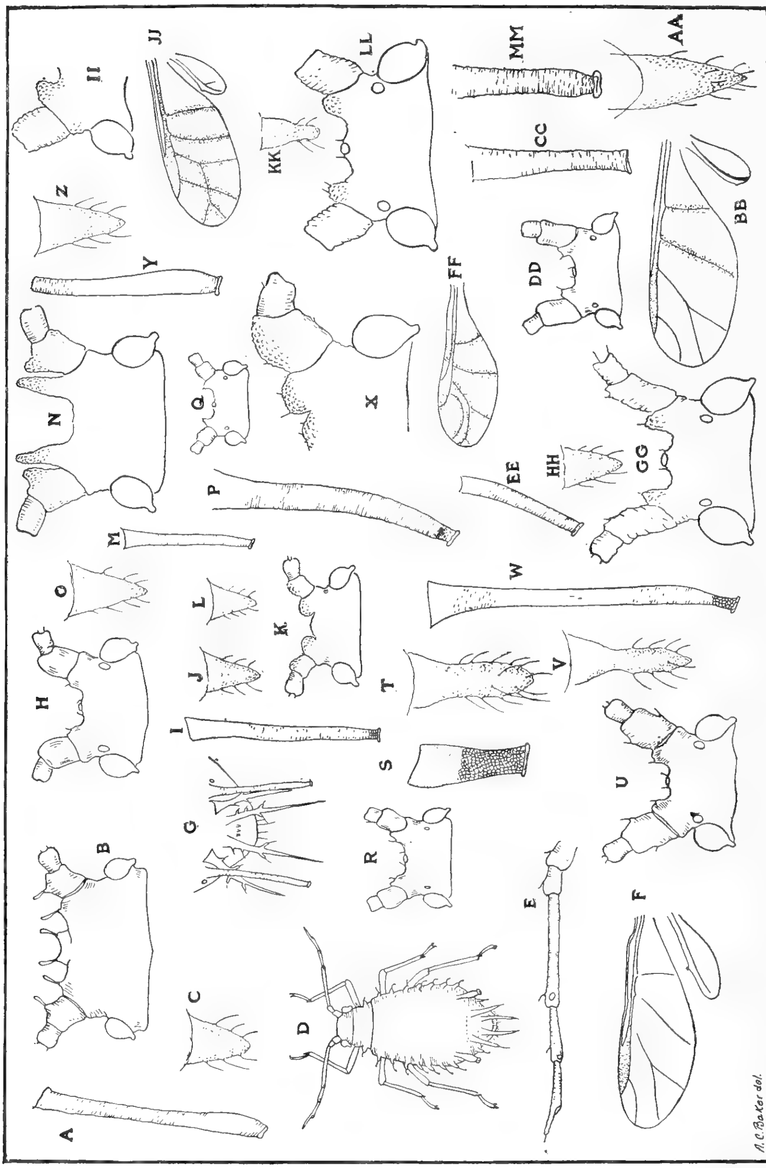
A.—*Acaudus lychnidis*, cornicle of alate form.
B.—*Acaudus lychnidis*, cauda of alate form.
C.—*Anuraphis amygdali*, cornicle of alate form.
D.—*Anuraphis amygdali*, cauda of alate form.
E.—*Anuraphis amygdali*, head of alate form.
F.—*Anuraphis carotae*, cornicle and cauda of alate form.
G.—*Aphis sambuci*, head of alate form.
H.—*Aphis sambuci*, cornicle of alate form.
I.—*Aphis sambuci*, cauda of alate form.
J.—*Brevicoryne brassicae*, cauda of alate form.
K.—*Brevicoryne brassicae*, cornicle of alate form.
L.—*Aspidaphis polygonii*, cornicle of alate form.
M.—*Aspidaphis polygonii*, cornicle more enlarged.
N.—*Aspidaphis polygonii*, cauda of apterous form.
O.—*Aspidaphis polygonii*, head of apterous form.
P.—*Atarsos grindeliae*, cornicle of alate form.
Q.—*Atarsos grindeliae*, head of alate form.
R.—*Atarsos grindeliae*, cauda of alate form.
S.—*Atarsos grindeliae*, tibia of alate form.
T.—*Brachycolus stellariae*, cornicle of alate form.
U.—*Brachycolus stellariae*, cauda of alate form.
V.—*Carolinaia cyperi*, cornicle of alate form.
W.—*Carolinaia cyperi*, cauda of alate form.
X.—*Cavariella pastinacae*, cornicle of alate form.
Y.—*Cavariella pastinacae*, cauda of alate form.
Z.—*Cavariella pastinacae*, tubercle of alate form.
AA.—*Hyadaphis xylostei*, cauda of apterous form.
BB.—*Hyadaphis xylostei*, cornicle of apterous form.
CC.—*Toxoptera aurantiae*, head of alate form.
DD.—*Toxoptera aurantiae*, cornicle of alate form.
EE.—*Toxoptera aurantiae*, cauda of alate form.
FF.—*Rhopalosiphum rufomaculata*, cornicle of alate form.
GG.—*Rhopalosiphum rufomaculata*, head of alate form.
HH.—*Rhopalosiphum rufomaculata*, cauda of alate form.
II.—*Rhopalosiphum nymphaeae*, cornicle of alate form.
JJ.—*Rhopalosiphum nymphaeae*, cauda of alate form.
KK.—*Pergandeidia ononidis*, cauda and cornicle of alate form.
LL.—*Pergandeidia trirhodus*, cauda of apterous form.
MM.—*Pergandeidia trirhodus*, cornicle of apterous form.
NN.—*Liosomaphis berberidis*, cornicle and cauda of apterous form.
OO.—*Liosomaphis berberidis*, cauda of alate form.
PP.—*Cryptosiphum artemesiae*, cornicle of apterous form.
QQ.—*Cryptosiphum artemesiae*, cauda of apterous form.
RR.—*Hyalopterus arundinis*, cornicle of alate form.
SS.—*Hyalopterus arundinis*, cauda of alate form.
TT.—*Hyalopterus deformans*, cauda of apterous form.
UU.—*Hyalopterus deformans*, cornicle of apterous form.
VV.—*Hyalopterus deformans*, cauda of alate form.
WW.—*Hyalopterus deformans*, cornicle of alate form.

PLATE VII.

A.—*Siphonatrophia cupressi*, apterous form.
B.—*Siphonatrophia cupressi*, wings.
C.—*Siphonatrophia cupressi*, antenna of alate form.
D.—*Siphonatrophia cupressi*, cauda of alate form.
E.—*Siphonatrophia cupressi*, antenna of apterous form.
F.—*Sanbornia juniperi*, apterous form.
G.—*Sanbornia juniperi*, wings.
H.—*Sanbornia juniperi*, antenna of alate form.
I.—*Sanbornia juniperi*, head of apterous form from beneath.
J.—*Sanbornia juniperi*, cauda of alate form.
K.—*Sanbornia juniperi*, cornicle.
L.—*Sanbornia juniperi*, tarsus.
M.—*Vesiculaphis caricis*, apterous form.
N.—*Vesiculaphis caricis*, cornicle of alate form.
O.—*Vesiculaphis caricis*, fore wing.
P.—*Vesiculaphis caricis*, antenna of alate form.
Q.—*Vesiculaphis caricis*, cauda of alate form.
R.—*Acanthaphis rubi*, apterous form.
S.—*Acanthaphis rubi*, head of apterous form.
T.—*Acanthaphis rubi*, cornicle of apterous form.
U.—*Acanthaphis rubi*, antenna of apterous form.



GENERIC CLASSIFICATION OF APHIDIDAE.



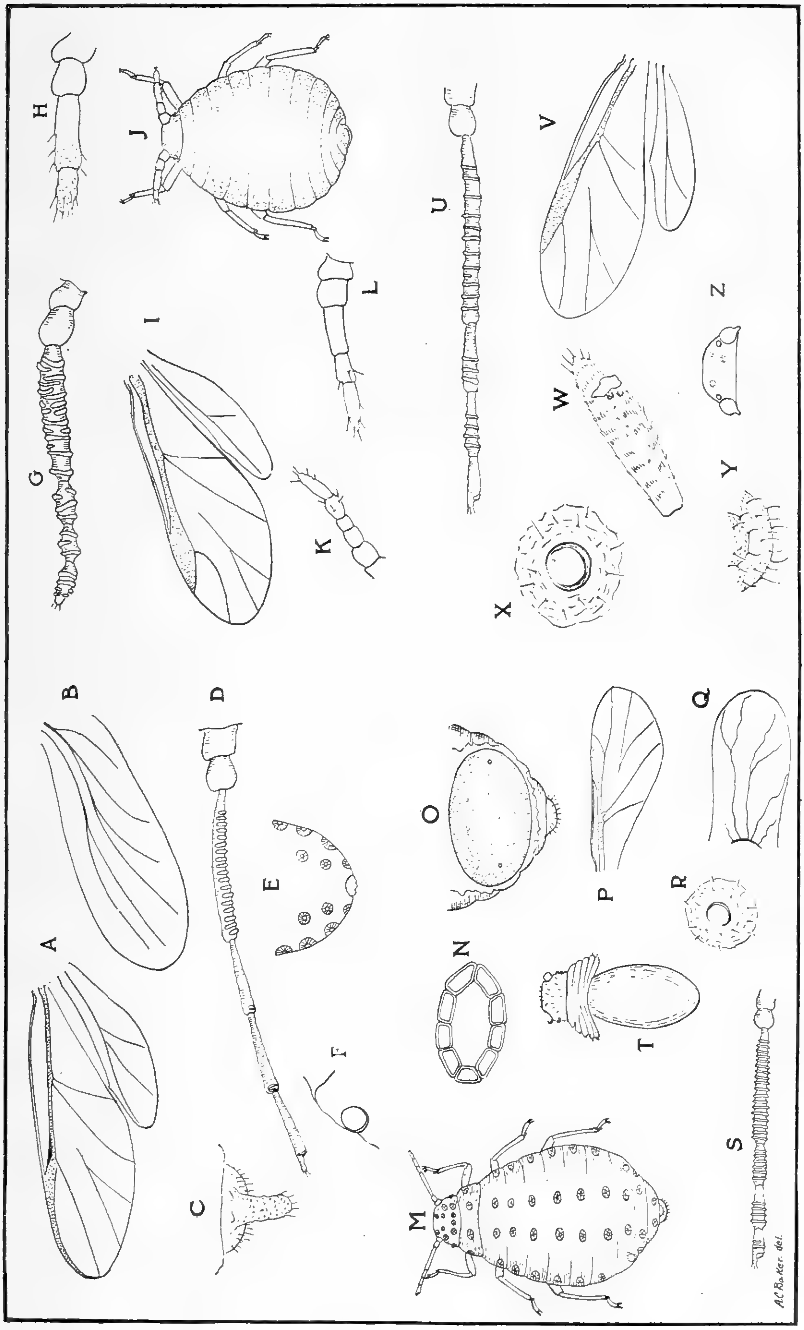
GENERIC CLASSIFICATION OF APHIDIDAE.

PLATE VIII.

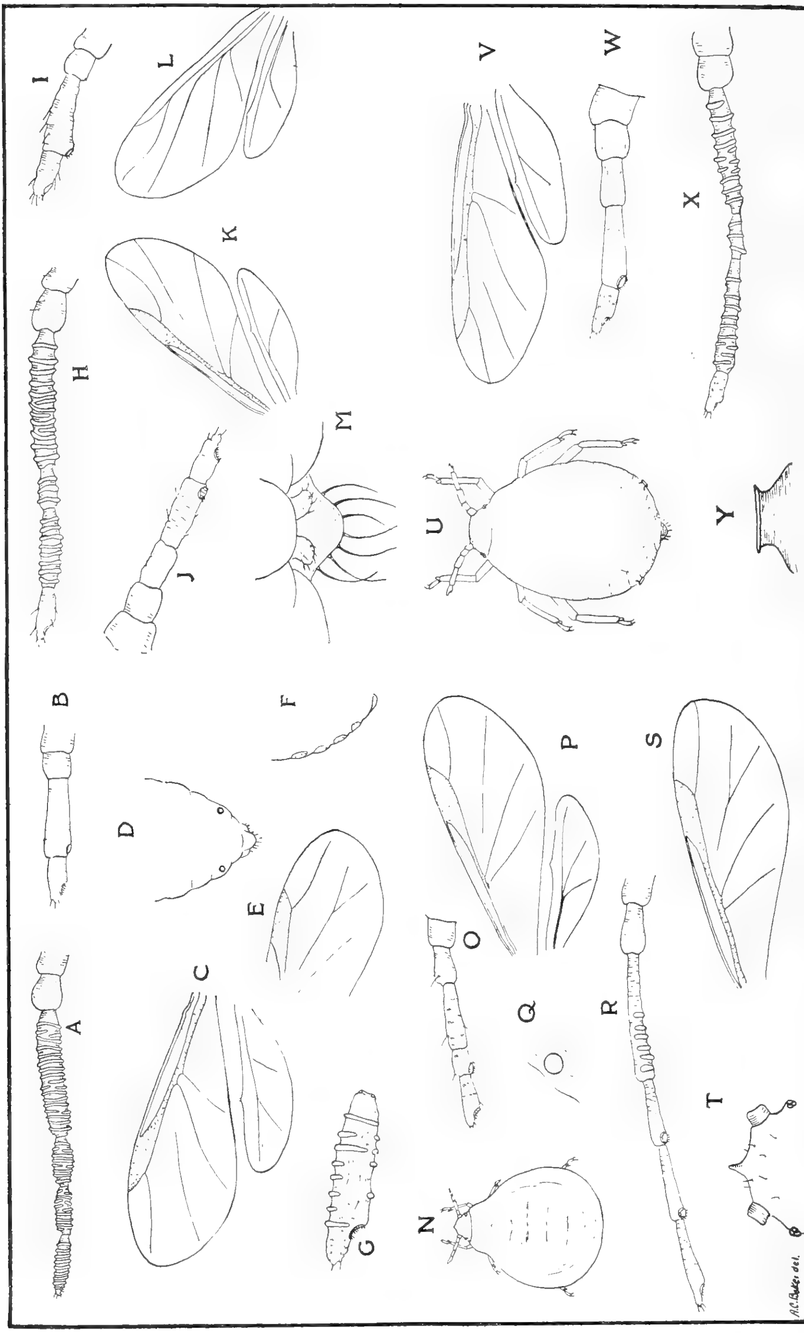
A.—*Capitophorus shepardiae*, cornicle of alate form.
B.—*Capitophorus shepardiae*, head of alate form.
C.—*Capitophorus shepardiae*, cauda of alate form.
D.—*Anomalaphis comperi*, apterous form.
E.—*Anomalaphis comperi*, antenna of apterous form.
F.—*Anomalaphis comperi*, wings.
G.—*Cervaphis schoutedeniae*, extremity of abdomen.
H.—*Illinoia liriodendri*, head of alate form.
I.—*Illinoia liriodendri*, cornicle of alate form.
J.—*Illinoia liriodendri*, cauda of alate form.
K.—*Myzus cerasi*, head of apterous form.
L.—*Myzus cerasi*, cauda of apterous form.
M.—*Myzus cerasi*, cornicle of alate form.
N.—*Phorodon humuli*, head of apterous form.
O.—*Phorodon humuli*, cauda of apterous form.
P.—*Phorodon humuli*, cornicle of apterous form.
Q.—*Phorodon humuli*, head of alate form.
R.—*Macrosiphonella sanborni*, head of alate form.
S.—*Macrosiphonella sanborni*, cornicle of alate form.
T.—*Macrosiphonella sanborni*, cauda of alate form.
U.—*Macrosiphum rosae*, head of alate form.
V.—*Macrosiphum rosae*, cauda of alate form.
W.—*Macrosiphum rosae*, cornicle of alate form.
X.—*Myzus persicae*, head of apterous form.
Y.—*Myzus persicae*, cornicle of alate form.
Z.—*Myzus persicae*, cauda of alate form.
AA.—*Microparsus variabilis*, cauda of alate form.
BB.—*Microparsus variabilis*, wings.
CC.—*Microparsus variabilis*, cornicle of alate form.
DD.—*Microparsus variabilis*, head of alate form.
EE.—*Idiopterus nephrolepidis*, cornicle of alate form.
FF.—*Idiopterus nephrolepidis*, fore wing.
GG.—*Idiopterus nephrolepidis*, head of alate form.
HH.—*Idiopterus nephrolepidis*, cauda of alate form.
II.—*Pentalonia nigronervosa*, head of apterous form.
JJ.—*Pentalonia nigronervosa*, wings.
KK.—*Pentalonia nigronervosa*, cauda of alate form.
LL.—*Pentalonia nigronervosa*, head of alate form.
MM.—*Pentalonia nigronervosa*, cornicle of alate form.

Plate IX.

A.—*Mindarus abietinus*, wings.
B.—*Mindarus abietinus*, fore wing showing tracheæ.
C.—*Mindarus abietinus*, cauda of alate form.
D.—*Mindarus abietinus*, antenna of alate form.
E.—*Mindarus abietinus*, abdomen of pupa.
F.—*Mindarus abietinus*, cornicle of alate form.
G.—*Colopha ulmicola*, antenna of alate form.
H.—*Colopha ulmicola*, antenna of stem mother.
I.—*Colopha ulmicola*, wings.
J.—*Colopha ulmicola*, apterous form.
K.—*Colopha ulmicola*, antenna of apterous form.
L.—*Colopha ulmicola*, antenna of apterous form.
M.—*Eriosoma lanigerum*, apterous form.
N.—*Eriosoma lanigerum*, wax plate.
O.—*Eriosoma lanigerum*, wax reservoir.
P.—*Eriosoma lanigerum*, fore wing.
Q.—*Eriosoma lanigerum*, wing pad showing tracheæ.
R.—*Eriosoma lanigerum*, cornicle.
S.—*Eriosoma lanigerum*, antenna of alate form.
T.—*Eriosoma lanigerum*, oviparous female, showing egg.
U.—*Georgia ulmi*, antenna of alate form.
V.—*Georgia ulmi*, wings.
W.—*Georgia ulmi*, distal segment of antenna of alate form.
X.—*Georgia ulmi*, cornicle of alate form.
Y.—*Georgia ulmi*, cauda and anal plate of alate form.
Z.—*Georgia ulmi*, head of alate form.



GENERIC CLASSIFICATION OF APHIDIDAE.



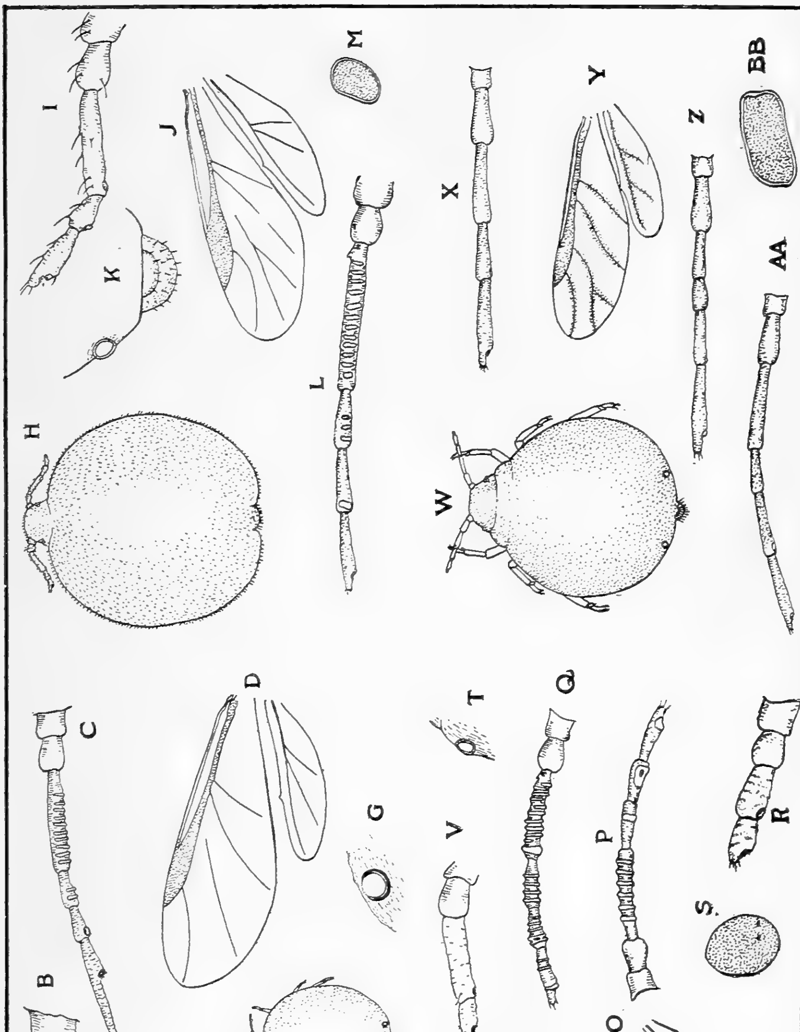
GENERIC CLASSIFICATION OF APHIDIDAE.

PLATE X.

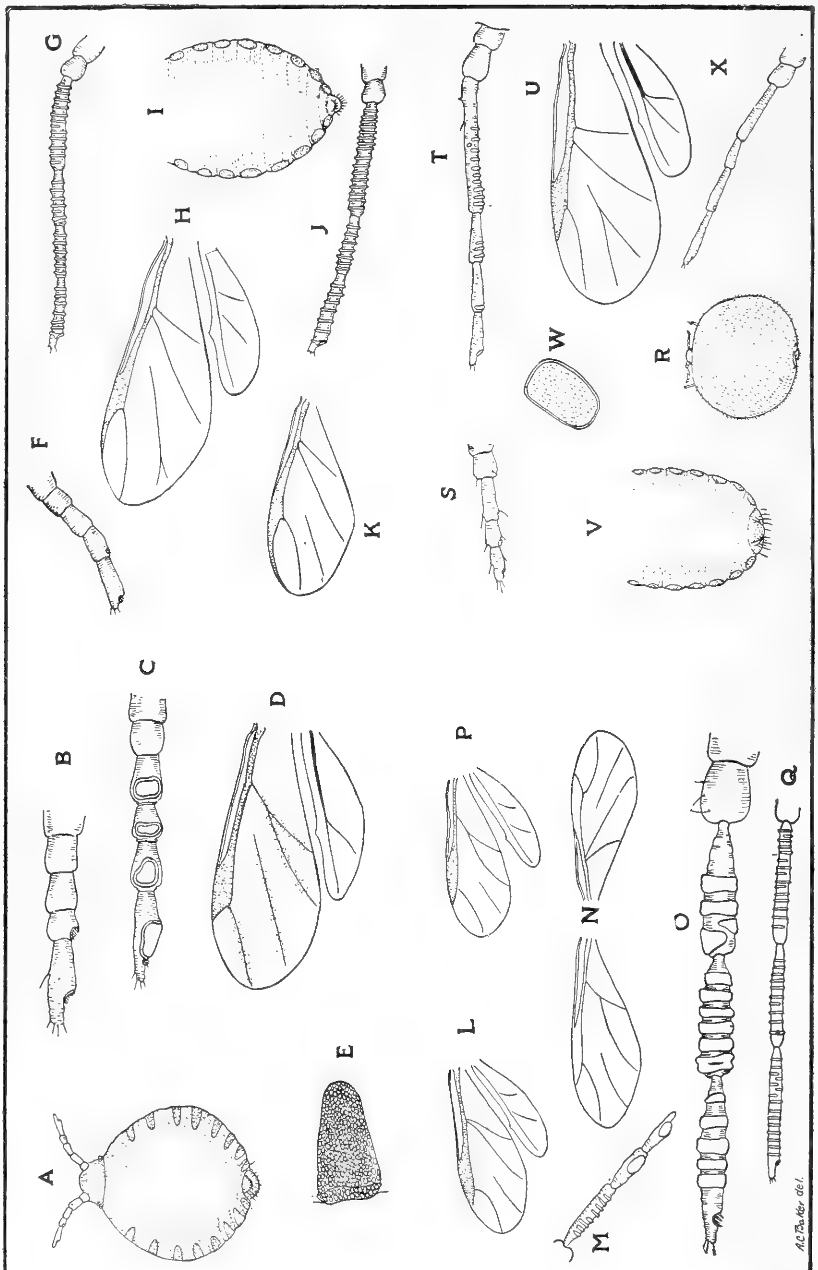
A.—*Gobaishia pallida,* antenna of alate form.
B.—*Gobaishia pallida,* antenna of stem mother.
C.—*Gobaishia pallida,* wings.
B.—*Gobaishia pallida,* abdomen of alate form showing cornicle.
E.—*Gobaishia pallida,* fore wing.
F.—*Gobaishia pallida,* abdomen of pupa.
G.—*Gobaishia pallida,* distal segment of antenna of alate form from above.
H.—*Tetraneura ulmifoliae,* antenna of alate form.
I.—*Tetraneura ulmifoliae,* antenna of stem mother.
J.—*Tetraneura ulmifoliae,* antenna of apterous form.
K.—*Tetraneura ulmifoliae,* wings.
L.—*Tetraneura ulmifoliae,* wings showing tracheæ.
M.—*Tetraneura ulmifoliae,* cauda and anal plate.
N.—*Cornaphis populi,* stem mother.
O.—*Cornaphis populi,* antenna of stem mother.
P.—*Cornaphis populi,* wings.
Q.—*Cornaphis populi,* cornicle of alate form.
R.—*Cornaphis populi,* antenna of alate form.
S.—*Cornaphis populi,* fore wing.
T.—*Cornaphis populi,* head showing horn.
U.—*Dryopeia bella,* apterous form.
V.—*Dryopeia bella,* wings.
W.—*Dryopeia bella,* antenna of apterous form.
X.—*Dryopeia bella,* antenna of alate form.
Y.—*Dryopeia bella,* cornicle of apterous form.

PLATE XI.

A.—*Mordwilkoja vagabunda*, stem mother.
B.—*Mordwilkoja vagabunda*, antenna of stem mother.
C.—*Mordwilkoja vagabunda*, antenna of alate form.
D.—*Mordwilkoja vagabunda*, wings.
E.—*Mordwilkoja vagabunda*, thorax of alate form.
F.—*Mordwilkoja vagabunda*, cauda of alate form.
G.—*Mordwilkoja vagabunda*, cornicle of alate form.
H.—*Asiphum* sp. stem mother.
I.—*Asiphum* sp. antenna of stem mother.
J.—*Pachypappella vesicalis*, wings.
K.—*Pachypappella vesicalis*, cornicles and cauda of alate form.
L.—*Pachypappella vesicalis*, antenna of alate form.
M.—*Pachypappella vesicalis*, wax plate.
N.—*Pemphigus bursarius*, antenna of stem mother.
O.—*Pemphigus bursarius*, wings.
P.—*Pemphigus bursarius*, antenna of alate form.
Q.—*Pemphigus bursarius*, antenna of alate form.
R.—*Pemphigus bursarius*, antenna of stem mother.
S.—*Pemphigus bursarius*, wax plate.
T.—*Pemphigus bursarius*, cornicle of alate form.
U.—*Pemphigus populicaulis*, antenna of stem mother.
V.—*Gobaishia ulmifuscus*, antenna of stem mother.
W.—*Phloeomyzus passerini*, apterous form.
X.—*Phloeomyzus passerini*, antenna of apterous form.
Y.—*Phloeomyzus passerini*, wings.
Z.—*Phloeomyzus passerini*, antenna of apterous form.
AA.—*Phloeomyzus passerini*, antenna of alate form.
BB.—*Phloeomyzus passerini*, wax plate.



GENERIC CLASSIFICATION OF APHIDIDAE.



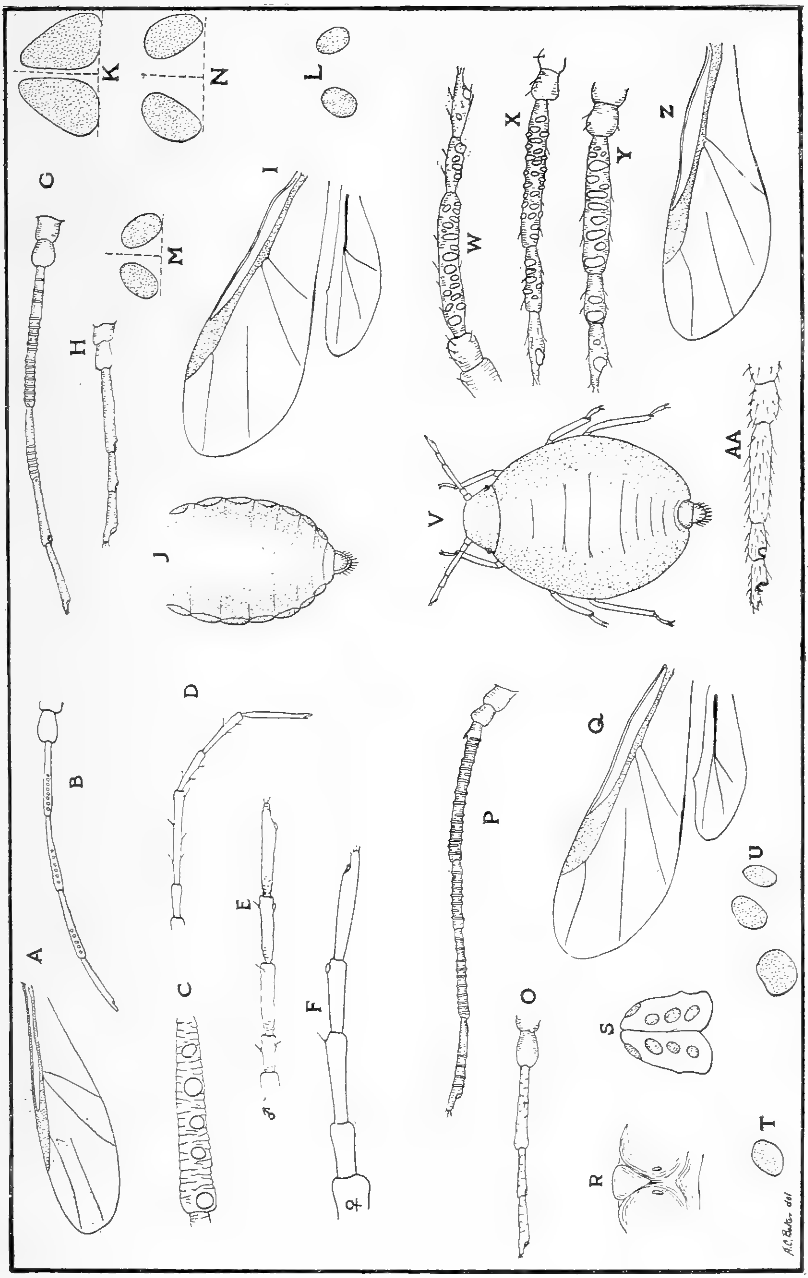
GENERIC CLASSIFICATION OF APHIDIDAE.

PLATE XII.

A.—*Aploneura lentici*, apterous form.
B.—*Aploneura lentici*, antenna of apterous form.
C.—*Aploneura lentici*, antenna of alate form.
D.—*Aploneura lentici*, wings.
E.—*Aploneura lentici*, abdominal wax plate.
F.—*Melaphis rhois*, antenna of apterous form.
G.—*Melaphis rhois*, antenna of alate form.
H.—*Melaphis rhois*, wings.
I.—*Melaphis rhois*, abdomen of alate form.
J.—*Melaphis rhois*, antenna of alate form.
K.—*Melaphis chinensis*, fore wing.
L.—*Nurudea ibofushi*, wings.
M.—*Nurudea ibofushi*, antenna of alate form.
N.—*Nurudea shiraii*, wings.
O.—*Nurudea shiraii*, antenna of alate form.
P.—*Nurudea rosea*, fore wing.
Q.—*Nurudea rosea*, antenna of alate form.
R.—*Asiphum tremulae*, stem mother.
S.—*Asiphum tremulae*, antenna of stem mother.
T.—*Asiphum tremulae*, antenna of alate form.
U.—*Asiphum tremulae*, wings.
V.—*Asiphum tremulae*, abdomen of alate form.
W.—*Asiphum tremulae*, wax plates.
X.—*Asiphum tremulae*, antenna of apterous form.

PLATE XIII.

A.—*Neoprociphilus attenuatus*, forewing.
B.—*Neoprociphilus attenuatus*, antenna of alate form.
C.—*Neoprociphilus attenuatus*, segment V of antenna of alate form.
D.—*Neoprociphilus attenuatus*, antenna of apterous form.
E.—*Neoprociphilus attenuatus*, antenna of male.
F.—*Neoprociphilus attenuatus*, antenna of oviparous female.
G.—*Prociphilus bumeliae*, antenna of alate female.
H.—*Prociphilus bumeliae*, antenna of stem mother.
I.—*Prociphilus bumeliae*, wings.
J.—*Prociphilus bumeliae*, abdomen of alate form.
K.—*Prociphilus bumeliae*, thoracic wax plates.
L.—*Prociphilus bumeliae*, head wax plates.
M.—*Prociphilus xylostei*, thoracic wax plates.
N.—*Prociphilus bumeliae* (*poscheringi*), thoracic wax plates.
O.—*Thecabius affinis*, antenna of stem mother.
P.—*Thecabius affinis*, antenna of alate form.
Q.—*Thecabius affinis*, wings.
R.—*Thecabius affinis*, thorax of alate form.
S.—*Thecabius affinis*, head wax plates of stem mother.
T.—*Thecabius affinis*, abdominal wax plate.
U.—*Thecabius affinis*, abdominal wax plates of stem mother.
V.—*Forda* sp., apterous form.
W.—*Forda olivacea*, antenna of alate form.
X.—*Forda trivialis*, antenna of alate form.
Y.—*Forda marginata*, antenna of alate form.
Z.—*Forda olivacea*, fore wing.
AA.—*Forda formicaria*, antenna of apterous form.



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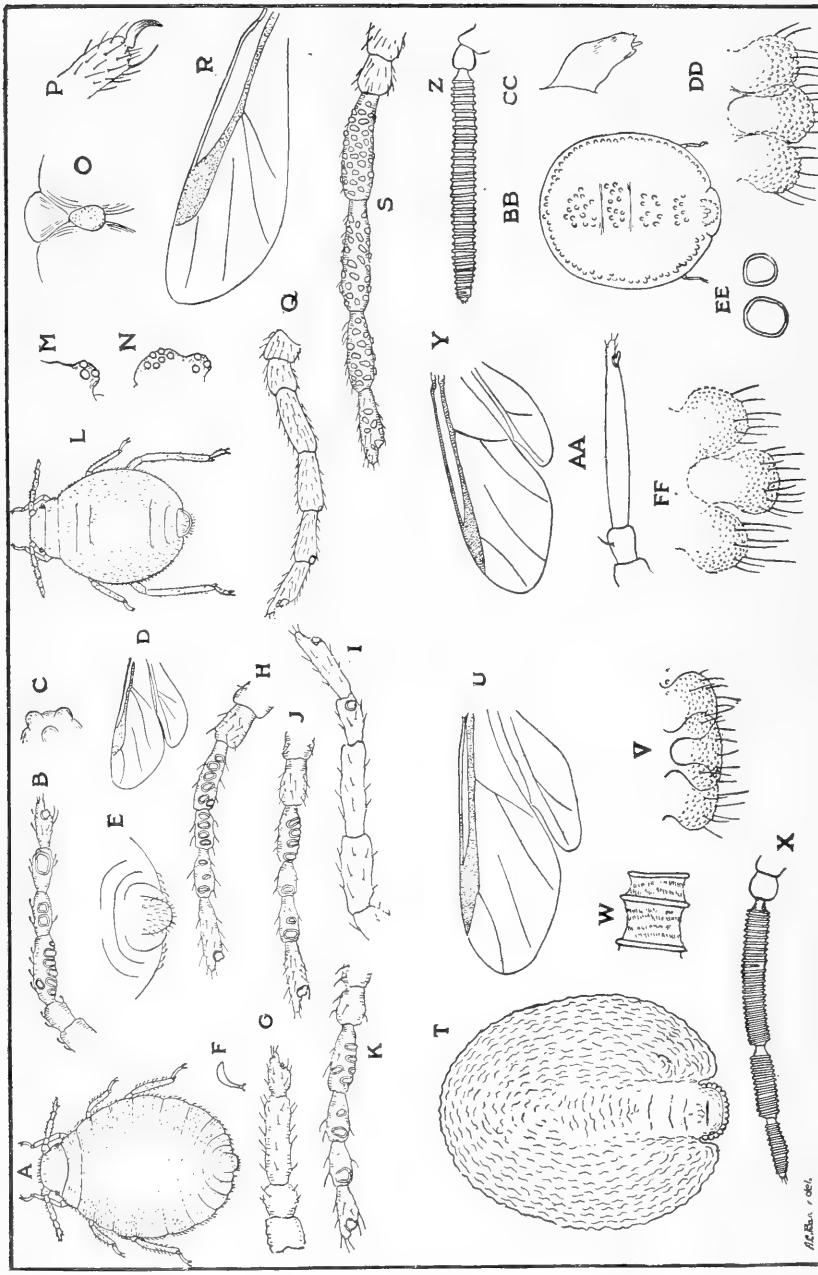


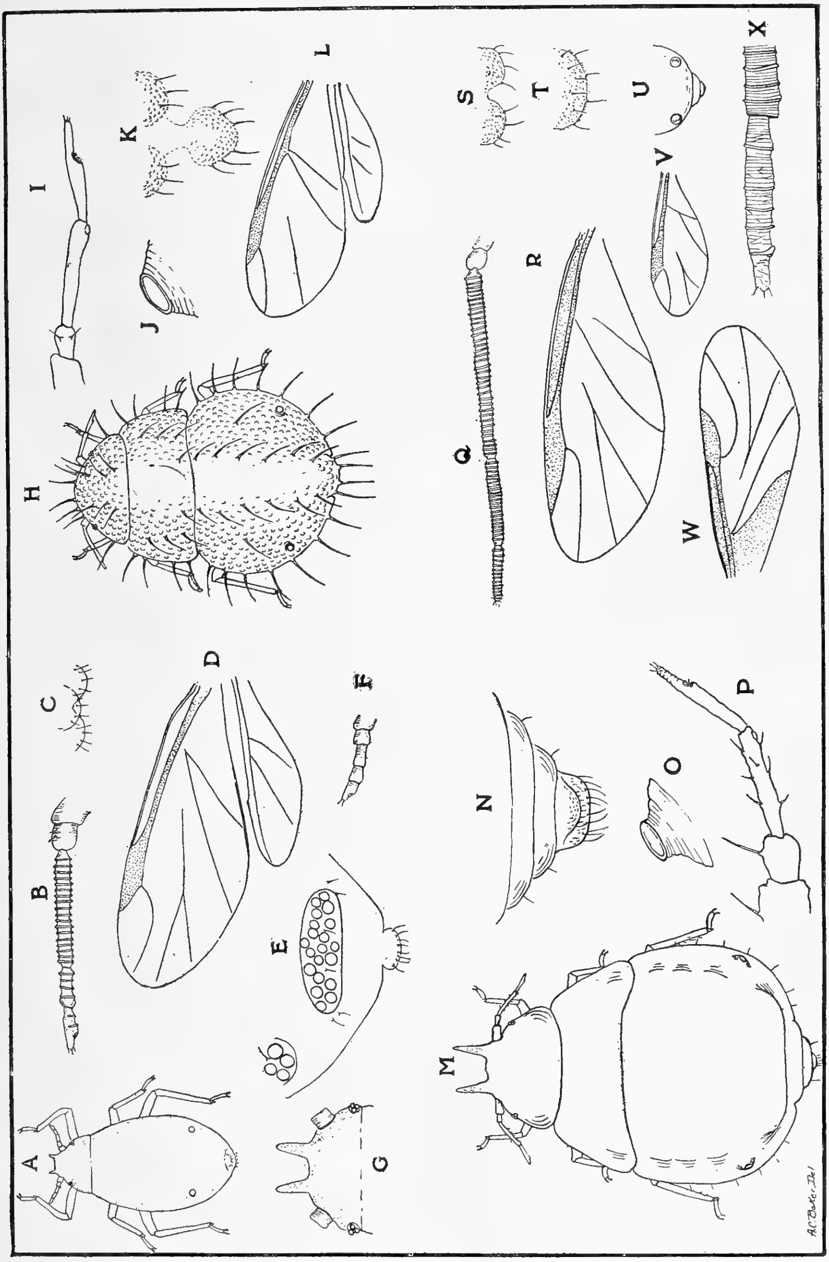
GENERIC CLASSIFICATION OF APHIDIDAE.

PLATE XIV.

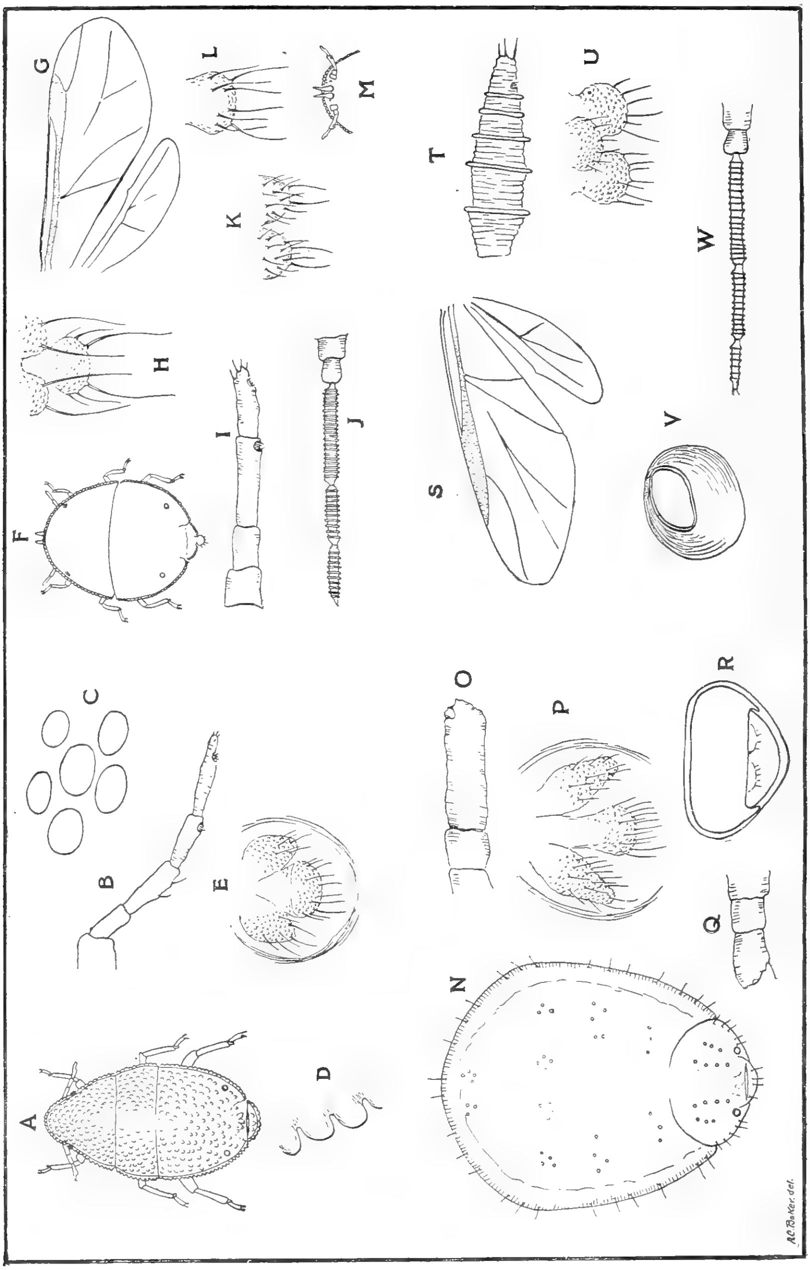
A.—*Geoica squamosa*, apterous form.
B.—*Geoica squamosa*, antenna of alate form.
C.—*Geoica squamosa*, eye of apterous form.
D.—*Geoica squamosa*, wings.
E.—*Geoica squamosa*, caudal extremity of apterous form.
F.—*Geoica squamosa*, squama.
G.—*Geoica squamosa*, four-segmented antenna of apterous form.
H.—*Geoica phaseoli*, antenna of alate form.
I.—*Geoica phaseoli*, antenna of apterous form.
J.—*Geoica radicicola*, antenna of alate form.
K.—*Geoica lucifuga*, antenna of alate form.
L.—*Paracletus cimiciformis*, apterous form.
M.—*Paracletus cimiciformis*, eye of apterous form.
N.—*Paracletus cimiciformis*, intermediate eye.
O.—*Paracletus cimiciformis*, median thoracic wax plate of alate form.
P.—*Paracletus cimiciformis*, foot of alate form with one claw.
Q.—*Paracletus cimiciformis*, antenna of apterous form.
R.—*Paracletus cimiciformis*, forewing.
S.—*Paracletus cimiciformis*, antenna of alate form.
T.—*Hamamelistes spinosus*, hibernating apterous form.
U.—*Hamamelistes spinosus*, wings.
V.—*Hamamelistes spinosus*, cauda and anal plate of alate form.
W.—*Hamamelistes spinosus*, antenna of alate form.
X.—*Hamamelistes spinosus*, portion of same, more enlarged.
Y.—*Hormaphis hamamelidis*, wings.
Z.—*Hormaphis hamamelidis*, antenna of alate form.
AA.—*Hormaphis hamamelidis*, antenna of stem mother.
BB.—*Hormaphis hamamelidis*, apterous form.
CC.—*Hormaphis hamamelidis*, antenna of apterous form.
DD.—*Hormaphis hamamelidis*, cauda and anal plate of apterous form.
EE.—*Hormaphis hamamelidis*, dorsal wax pores.
FF.—*Hormaphis hamamelidis*, cauda and anal plate of alate form.

PLATE XV.

A.—*Oregma lanigera*, apterous form.
B.—*Oregma lanigera*, antenna of alate form.
C.—*Oregma lanigera*, cauda and anal plate of alate form.
D.—*Oregma lanigera*, wings.
E.—*Oregma lanigera*, end of abdomen of apterous form.
F.—*Oregma lanigera*, antenna of apterous form.
G.—*Oregma bambusae*, head of apterous form.
H.—*Glyphinaphis bambusae*, apterous form.
I.—*Glyphinaphis bambusae*, antenna of apterous form.
J.—*Glyphinaphis bambusae*, cornicle of apterous form.
K.—*Glyphinaphis bambusae*, cauda and anal plate.
L.—*Mansakia miyabei*, wings.
M.—*Ceratoglyphina bambusae*, apterous form.
N.—*Ceratoglyphina bambusae*, cauda and anal plate.
O.—*Ceratoglyphina bambusae*, cornicle of apterous form.
P.—*Ceratoglyphina bambusae*, antenna of apterous form.
Q.—*Astegopteryx distychii*, antenna of alate form.
R.—*Astegopteryx distychii*, fore wing.
S.—*Astegopteryx distychii*, anal plate of alate form.
T.—*Astegopteryx distychii*, cauda of alate form.
U.—*Astegopteryx distychii*, end of abdomen.
V.—*Astegopteryx styracophila*, fore wing.
W.—*Astegopteryx gallarum*, fore wing.
X.—*Astegopteryx gallarum*, tip of antenna of alate form.



GENERIC CLASSIFICATION OF APHIDIDAE.



GENERIC CLASSIFICATION OF APHIDIDAE.

PLATE XVI.

A.—*Aleurodaphis blumeae*, apterous form.
B.—*Aleurodaphis blumeae*, antenna of apterous form.
C.—*Aleurodaphis blumeae*, dorsal wax pores.
D.—*Aleurodaphis blumeae*, margin.
E.—*Aleurodaphis blumeae*, cauda and anal plate.
F.—*Cerataphis lataniae*, apterous form.
G.—*Cerataphis lataniae*, wings.
H.—*Cerataphis lataniae*, cauda and anal plate of apterous form.
I.—*Cerataphis lataniae*, antenna of apterous form.
J.—*Cerataphis lataniae*, antenna of alate form.
K.—*Cerataphis lataniae*, anal plate of alate form.
L.—*Cerataphis lataniae*, cauda of alate form.
M.—*Cerataphis lataniae*, head of apterous form, central view.
N.—*Thoracaphis arboris*, apterous form.
O.—*Thoracaphis arboris*, antenna of apterous form.
P.—*Thoracaphis arboris*, cauda and anal plate of apterous form.
Q.—*Thoracaphis ficus*, antenna of apterous form.
R.—*Thoracaphis ficus*, extremity of abdomen, apterous form.
S.—*Thoracaphis castaneae*, wings.
T.—*Thoracaphis castaneae*, distal segment of antenna of alate form.
U.—*Thoracaphis castaneae*, cauda and anal plate of alate form.
V.—*Thoracaphis castaneae*, cornicle of alate form.
W.—*Thoracaphis castaneae*, antenna of alate form.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 827

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief

Washington, D. C. ▲ **May 26, 1921**

THE CUT-OVER PINE LANDS OF THE SOUTH FOR BEEF-CATTLE PRODUCTION.

By F. W. Farley and S. W. Greene, *Animal Husbandry Division, Bureau of Animal Industry.*

CONTENTS.

In the summer of 1917 the Bureau of Animal Industry, United States Department of Agriculture, in cooperation with the Mississippi experiment station, established at Collins, Miss., a branch beef-cattle experiment station to determine practical methods to follow in growing beef on cut-over pine lands. Soon after the station was established and plans for the work were put under way it was realized that, before further experiments were conducted, more definite information should be obtained concerning the resources and possibilities for beef-cattle production on cut-over pine lands.

S. W. Greene, who was in charge of the work at Collins, was detailed by the Bureau of Animal Industry to make a survey of the "Piney Woods" region and collect information along these lines. The data collected by Mr. Greene are included in this publication.

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Later, the station was transferred from Collins to McNeill, Miss., where the work is to be conducted on a broader scale than was possible at Collins.

EXTENT OF THE CUT-OVER LANDS.

The cut-over pine lands of the South lie within the area known as the Coastal Plain. This section is spoken of locally as the "Piney Woods." It includes the southeastern portion of South Carolina, most of Florida, the southern parts of Georgia, Alabama, and Mississippi, the central and northern parts of Louisiana, and parts of southeastern Texas and of southern Arkansas. At present the total area is estimated at 100,000,000 acres and is being increased about 10,000,000 acres annually, as additional land is cut over. One company alone in Louisiana requires a cut of 80 acres daily to supply its mills. It is estimated that ultimately the area of the cut-over lands will reach 250,000,000 acres.

A bare statement of figures does not readily present the vastness of such an area. When comparisons are made the cut-over lands appear as a veritable empire. The area represents an acreage more than half that of the State of Texas, or equal to the combined acreage of Georgia, Alabama, and Mississippi. Much of all this great area is unused and unproductive.

The sandy soil of sedimentary origin which constitutes the Coastal Plain is the natural habitat of the long-leaf yellow pine (*Pinus palustris*), which once covered the territory with a heavy growth to the exclusion of practically all other timber, except on the alluvial land along streams, which is forested with hardwood trees. This species of pine is of first importance to the naval-stores industry, as it is the main species in the United States that is tapped for turpentine.

Long-leaf pine also makes a very high grade of lumber, and since the late nineties lumbering has superseded all other industries in the section mentioned. In 1909 the cut of southern yellow pine was 36.6 per cent and in 1913 it was 38.7 per cent of the entire cut of all species of the country.[1]

Because of the immense scale of lumbering operations the land has been rapidly denuded of the timber, and as practically all timbered lands were in the hands of lumbermen whose interest was in the timber, the lands remained as the woods crews left them—covered with stumps and strewn with crowns, unmerchantable logs, and small timber. Little thought was given to their future development as agricultural or grazing lands. In other words, the cut-over condition of the lands is a by-product of lumbering. With the end

[1] Bureau of Crop Estimates and Forest Service, U. S. Department of Agriculture.

Fig. 1.—Native pasture typical of the cut-over pine lands of the South.

of lumbering operations in sight, with increasing taxes on the nonproductive land, and with no market to assimilate the oversupply, the owner of such lands was presented with an acute problem which resolved itself into the question of letting the land revert to the State

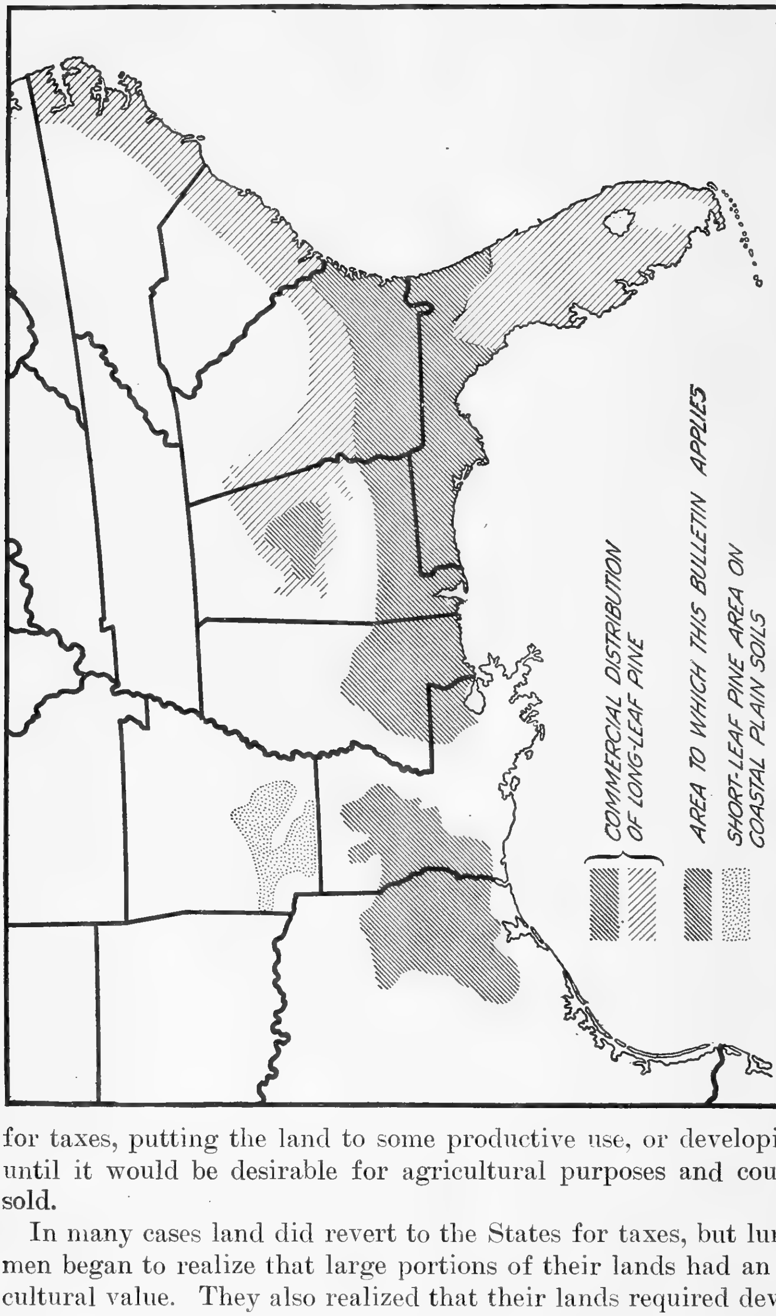

Fig. 2.—General distribution of long-leaf pine, showing approximately the area covered in this bulletin.

for taxes, putting the land to some productive use, or developing it until it would be desirable for agricultural purposes and could be sold.

In many cases land did revert to the States for taxes, but lumbermen began to realize that large portions of their lands had an agricultural value. They also realized that their lands required development either to make them productive or to demonstrate their value and place them in a form so that they would be assimilated as farms on a large scale. However, considerable raw cut-over land is being sold to settlers.

Increasing interest in the development of cut-over lands was responsible for the "Cut-Over Land Conference of the South," which was held at New Orleans, La., in April, 1917. More than 400 large landowners and agricultural experts, both State and Federal, were present at the meeting. That the utilization of cut-over lands in the near future depended largely upon the use of grazing animals was the consensus of opinion. The meeting also brought out the fact that very little definite information was available concerning the possibilities of the region for cattle production.

The map, figure 2, shows the area discussed in this report. The shaded portions represent the approximate commercial distribution of the long-leaf yellow pine. The heavily shaded portion indicates the area in which the larger part of the land is unused cut-over land and the region to which this report particularly applies. The shaded portion in Arkansas is forested with shortleaf pine but lies within the Coastal Plain, and the soils and conditions are similar to the upper Coastal Plain region east of the Mississippi River.

SURVEY OF THE CUT-OVER LANDS.

OBJECTS AND PLAN OF PROCEDURE.

The survey of the Piney Woods region, herein reported, was made to secure first-hand information as to the resources and possibilities of the cut-over pine lands of the South for beef-cattle production and was undertaken with the following points in view:

1. To determine the status of the beef-cattle industry.
2. To determine the adaptation of the region for the production of beef cattle.
3. To determine what recommendations for improvement of present conditions should be made.
4. To determine what experimental work with beef cattle is needed.

A study was made of available literature pertaining to the Piney Woods, including soils, crops, grasses, forage, and experimental work with beef cattle. The agricultural colleges were then visited and with their cooperation an itinerary was mapped out for trips of inspection to the farms of the principal cattlemen, lumber companies, and development associations in the Piney Woods of Arkansas, Louisiana, Mississippi, Alabama, Georgia, and Florida. Typical undeveloped tracts and virgin forests were also visited in the different States. In addition questionnaires were mailed to all county agents, all owners of pure-bred beef cattle, so far as lists were available, and all the larger lumber companies.

STATUS OF THE BEEF-CATTLE INDUSTRY.

NUMBER AND VALUE OF CATTLE.

Table 1 shows the number of cattle other than milk cows for 1910, and for the last 4 years in the 6 States included in this report.

TABLE 1.—*Number and value of cattle other than milk cows in States with large areas of Piney Woods.*[1]

State.	Number Jan. 1—				Census, Apr. 15, 1910.	Value per head Jan. 1, 1920.
	1920	1919	1918	1917		
Georgia	771,000	763,000	727,000	686,000	666,000	$27.20
Florida	945,000	936,000	891,000	865,000	611,000	27.30
Alabama	842,000	851,000	760,000	534,000	534,000	22.90
Mississippi	716,000	708,000	644,000	575,000	580,000	23.50
Louisiana	725,000	690,000	600,000	525,000	510,000	29.30
Arkansas	691,000	678,000	640,000	560,000	599,000	24.40
Total	4,690,000	4,626,000	4,262,000	3,745,000	3,500,000	[2] 25.77

[1] Figures for 1910 are taken from the Census report; other figures from Bureau of Crop Estimates, U. S. Department of Agriculture.
[2] Average.

This table presents some interesting points relative to the size and growth of the cattle industry and the values of cattle. The figures given are for the entire States, but the points brought out by the table are pertinent as applied to the Piney Woods sections. It will be noticed that the increase in the number of cattle during the last three years has been rapid as compared with the total increase from 1910 to 1916. The year 1910 marked the beginning of greater interest in the beef-cattle industry. About this time the menace of the boll weevil to the one-crop system of cotton farming turned attention to live stock. The growth from that time has been steady. The growth has been more rapid in the last four years because more area has been freed from ticks, and higher prices have been paid for cattle.

Although the cattle industry is growing rapidly, the number of cattle is proportionately far below that of other cattle-producing States and is only a fraction of the possibilities.

On January 1, 1920, the number of cattle in the States named was about one-ninth the total number for the United States, but their value was only one-sixteenth of the total value. The average value of cattle per head for the six States at that time was $25.77, while the average value per head for the six leading cattle States, viz, Texas, Nebraska, Iowa, Kansas, Missouri, and Minnesota, was $44.27. The difference in price indicates the difference in size and quality.

The fact that the Piney Woods region produces cattle of such relatively small value is due to a number of factors, the chief ones being the character of the agriculture, the occupation of lumbering, and the cattle tick.

The character of the agriculture of the Piney Woods region has had considerable effect on the number of cattle produced. Like other portions of the South, the section followed largely a one-crop system, growing cotton for a cash crop, and neglecting the raising of winter feeds and the saving of hay. Clearing the land of stumps was the main difficulty in preparing land for cultivation, and such small areas as were cleared were planted to cotton, sugar cane, peanuts, and sweet potatoes, grass being fought as a deadly enemy.

From the middle nineties until the present time the lumber industry has overshadowed all others; considerable numbers of the people turned from farming to lumbering as an occupation, and farms were often neglected. Lumbering did not diminish the area of grazing lands, but the quality of the ranges deteriorated. With the removal of the virgin pine a thick undergrowth of scrub oak or young pine, depending upon the kind of soil, rapidly covered the land; "down" timber left from logging covered much of the ground and fires became more destructive, destroying most of the "switch" cane, on which the cattle depended for winter grazing, and preventing the spread of desirable pasture plants. The chief demand for cattle during this time was for work oxen.

As large tracts of the cut-over sections are owned by lumber syndicates and sawmill companies which have been interested chiefly in the timber value of their lands, efforts have been made in relatively few instances toward agricultural development. The cut-over lands were left open and were used for grazing the native cattle, but the system was not one that would induce large operations or encourage the entrance of outside cattlemen.

The cattle tick has not only been responsible for large losses of cattle, but the quality of the cattle produced in ticky territory and the necessary restrictions placed on their shipment have affected the market for cattle from these sections to such an extent that there was no inducement for greater production. Before the Revolutionary War, restrictions were placed on southern cattle being driven into the Northern States, as it had become known that they carried a disease which was fatal to northern cattle and which afterwards became known as Texas fever.

Even under such adverse conditions considerable numbers of cattle were maintained and in many cases they furnished the chief source of income. Prior to the building of the sawmills, the Piney Woods region was frequently referred to as the "cow country." With the disappearance of the sawmills in cut-over sections, interest in farming has revived during the last few years, and following the eradication of the cattle tick there has been a rapid increase in the number of cattle.

Widespread use of the velvet bean for winter forage and feed has done more to increase the number of cattle than any other factor except tick eradication. In many sections cattle have been increased solely for the purpose of utilizing the enormous crops of velvet beans, which could be marketed in no other way.

SIZE AND QUALITY OF CATTLE.

The native Piney Woods cattle are of very inferior quality, small in size, of poor conformation, and are what the feeder would term "cold blooded," as they do not respond readily to feed. Although these cattle are compact and show a good dressing percentage when fattened and slaughtered, the weight is too much forward, and there is a small percentage of valuable cuts. Mature cows average about 400 or 500 pounds, and steers from 3 to 5 years old average from 600 to 750 pounds.

The following table shows the average live weight of cattle slaughtered at Jacksonville, Fla., New Orleans, La., and East St. Louis, Ill., during 1918:

TABLE 2.—*Average weight of cattle slaughtered at three markets in 1918.*

Class of cattle.	Jacksonville, Fla.	New Orleans, La.	East St. Louis, Ill.
	Pounds.	*Pounds.*	*Pounds.*
Canners	462	525	730
Cutters	462	600	745
Mature steers	(1)	750	1,000

[1] Very few mature native steers slaughtered and no separate record kept.

Table 2 furnishes an interesting comparison of the weights of Florida cattle and those of cattle of the Piney Woods farther west with cattle received at East St. Louis, one of the larger markets for cattle from a large territory. Canners and cutters at Jacksonville, Fla., were nearly 100 pounds lighter than at New Orleans and more than 200 pounds lighter than at East St. Louis. Few native steers were slaughtered at Jacksonville, but they were at least 300 to 350 pounds lighter than those at East St. Louis, or 150 pounds lighter than at New Orleans.

The greatly increased interest in better cattle is shown by the fact that out of 65 head of pure-bred Hereford cattle sold at public auction at the Kansas City Royal Show in 1918, 18 head were from Piney Woods herds. That most of the cattle went to northern breeding herds, whence the original stock came, is evidence of their merit.

The theory, which has had wide circulation in the South, that the small size and poor quality of native cattle in general are due to lack of feed and care and not to heredity or breeding, is contrary to the established laws of heredity. Such a theory if given general credence would greatly retard the improvement of the cattle through the introduction of improved blood.

The foundation stock of the native cattle was probably early Spanish importations and the original cattle themselves were small. They have remained small and of inferior quality, principally because of failure to make good selection and to introduce better blood.

Proper use of feed and care is no doubt a very important factor in the development of the individual, but the size and quality ac-

Fig. 3.—Native "Piney Woods" steers in the feed lot.

quired through feeding are not transmitted to the offspring and no continued improvement can be made by feed and care alone without selection and the use of improved blood. However, the fact that no continued improvement can be made in the size or quality of cattle through the influence of feed and care alone is not an argument for not caring for the native cattle, as feed is the most important factor in developing the individual. Certainly the native cattle may be made to weigh much more by proper feeding, but can not be made to approach the weight of improved cattle raised under the same conditions.

The argument often advanced that pure-bred animals put under the same conditions as the native cattle will rapidly deteriorate into scrubs is not true, so far as heredity is concerned, for they will transmit the power to respond to feed and will far surpass the scrub if given proper feed and care. In other words, the pure-bred animal has been developed through long-continued breeding and selection to intensify the quality of responding to plentiful feed and converting it into meat of the most value, and that quality has become a fixed characteristic.

If a pure-bred or grade animal is kept under the same conditions to which the native cattle have been subjected, all the inherent advantage of responding to feed will be lost in that individual for the time being, as it will be subjected to an environment to which it is entirely unsuited and to which the native cattle have adapted themselves through generation after generation of natural selection and the "survival of the fittest." It is necessary that the native cattle should be hardy animals, and were it not for the powerful influence exerted by heredity to maintain the offspring true to the ancestors and not to the individual, the strain of native cattle would have run out long ago because of the ravages of the cattle tick, lack of feed, breeding immature animals, and inbreeding.

Prior to the Civil War large plantation owners took pride in their cattle and brought in pure-bred bulls, mostly Devons and Shorthorns. The steers with Devon blood were prized as work oxen, on account of their endurance and easy-keeping qualities. Traces of the Devon blood may still be seen in many of the native cattle. Brahman blood was also introduced along the coast, and some native cows are found showing Brahman characteristics. For a good many years very little improved beef blood was introduced. Considerable numbers of Jersey bulls were brought in, however, and when crossed with the native cows produced animals inferior to the native for beef purposes.

The cattle tick has had a far-reaching effect on the native cattle. Cattle heavily infested with ticks have been lowered in vigor and vitality to such an extent that they have not been able fully to utilize the grazing. When infested with ticks through the summer the cattle are in poor condition to stand the hard period of the winter months when grazing is scarce. This is especially true of young animals which are badly handicapped during the first 2 years of growth. It is not uncommon in a ticky country to see a yearling calf so emaciated from ticks as to go down when driven and be unable to stand even when assisted to its feet.

Further, with no provisions for winter feed, native cattle are forced to go through a period of semistarvation each year and during that time they lose a large part of the gains made in the more favorable grazing season. This system is particularly hard on young cattle during their first 2 winters, and they become so stunted that it requires 1 or 2 years longer to reach mature size than it would if they were supplied feed for continuous growth. A growing animal subjected to such annual periods of semistarvation takes much longer to reach mature size. The experience may be so rigorous as seriously to affect its health and vigor. Then, again, this period of semistarvation comes at a time when cows are heavy with calf, and as a result calves are not so strong when dropped as they would be if their dams were in good condition.

Cows are left to wean their calves and it is not uncommon to see a cow suckling a yearling. No separation is made of heifers and bulls, and as a result the former are allowed to "take up" and drop calves when under age and undersized. Breeding immature heifers seriously retards their growth and final development, and there is considerable evidence that the continuation of such a practice will eventually reduce the size of the animals in a herd. Under such a system there has been continual inbreeding, but the comparative effect of inbreeding on size and quality no doubt has been overemphasized in many cases. Inbreeding tends to intensify bad points, but it also intensifies desirable points, and possibly the intensification of the hardiness of the animals has offset any bad effects under natural selection.

"Topping" or selecting the best cattle for sale instead of culling has tended to decrease size and quality. This practice has been followed especially in Florida, where for a great many years the bulls were "topped" for export to Cuba for fighting purposes. It has had a very marked effect on the native cattle of Florida, as they are noticeably smaller and of a quality inferior to those of other sections of the Piney Woods to the north and west.

WORK ACCOMPLISHED IN IMPROVING NATIVE CATTLE.

The greatest step leading to the improvement of the native cattle has been the eradication of the cattle tick. In ticky country the importation of a pure-bred bull from tick-free territory is almost sure to be followed by death from tick fever, on exposure to native cattle or open pasture. Following the local county and State-wide dipping of cattle, the danger of death from tick fever is practically eliminated. The eradication of the ticks has also greatly improved the thrift of the native cattle and allows better utilization of the pastures. The cattle tick has been a great handicap and the advantages of its eradication could be enumerated at great length. It is sufficient to say that the tick is disappearing rapidly and the beneficial results are being demonstrated and recognized.

Although the value of pure-bred bulls for improving the native cattle was generally recognized, their number has increased slowly.

Few men in each county owned sufficient numbers of cows to induce them to purchase a bull and only the most progressive men have been purchasers.

Before the introduction of pure-bred bulls, improvement by selection was usually a negative quantity, the cow herds being topped for market. Where grading up with good bulls is now being practiced, however, the selection of the cow herd has been given consideration and the herds are being culled each year instead of topped.

With more attention to farming, methods of management have been improved, especially in the matter of providing winter feed and forage. Since the introduction of velvet beans practically all farmers are providing winter forage. Better management in other respects usually has resulted from the introduction of better blood.

NATIVE CATTLE FOR FOUNDATION HERDS.

Men familiar with the early western ranges state that the Piney Woods cows are equal to or superior to the native Texas cows, from which a very high grade of cattle has been evolved. That the native cows are well adapted to grading up through the use of pure-bred bulls has been demonstrated in every case where a good bull has been used.

The improvement is very marked in the first cross as to uniformity in both color and type. There is a marked change in the width, depth, and size of bone, the first cross resulting in an animal being closer to the ground and more nearly the beef type in every respect. The hardiness of the native cattle has become fixed to such a degree that there is little doubt that this quality is transmitted to some extent to grade animals produced by crossing the cows with pure-bred bulls.

In Louisiana 500 head of first-cross "weaners" in one bunch were observed. These calves were from pure-bred Hereford bulls out of native cows of all colors. The calves were as uniform in color and type as could be desired and they had the general appearance of beef animals. The same results from smaller numbers were observed in every section of the Piney Woods.

In Alabama one breeder has been grading up by the use of a pure-bred bull for the last 15 years and his herd of 178 head of grade Herefords now ranges from one-half to fifteen-sixteenths pure bred. Practically half of his herd could hardly be distinguished from pure breds. The records of these cattle have been followed closely. The yearlings now produced from high-grade cows weigh 200 pounds more than native yearlings under the same conditions as to pasture and feed. The increase in weight has been brought about by the continued use of a pure-bred sire and the proper selection and culling of females.

A Florida breeder has been grading up the native cows with pure-bred Shorthorn bulls for 15 years and his present herd is uniformly good. In his herd he has the original first-cross cow, called Old Blue, and her granddaughters and great-granddaughters, and the last could not be picked out from his pure-bred heifers.

Like results have been obtained by other breeders with sufficient numbers of cattle to leave no doubt as to the value of the native cow for foundation herds. With proper selection and 10 to 15 per cent culling each year, native cows should be a valuable asset for increasing the herds.

FIG. 4.—A grade heifer three crosses removed from a "Piney Woods" cow. Note the "growthy" appearance, the scale, and size of bone.

ADAPTATION OF CUT-OVER LANDS FOR BEEF CATTLE.

For the economic production of beef cattle, a country must furnish abundant grazing, ample water supply, soils capable of producing cheap winter feeds or forage, and convenient transportation to markets. These requirements may be readily fulfilled in the Piney Woods, yet, as pointed out later, immediate results must not be expected. The region needs general development and even then cattle owners must understand local problems in handling their stock and growing feed before they can expect best results.

CLIMATE.

In addition to the factors mentioned, the Piney Woods region has the advantage of a mild climate with long summers and short, mild winters. The average date of the last killing frost in the spring is March 10, and the first killing frost in the fall is after

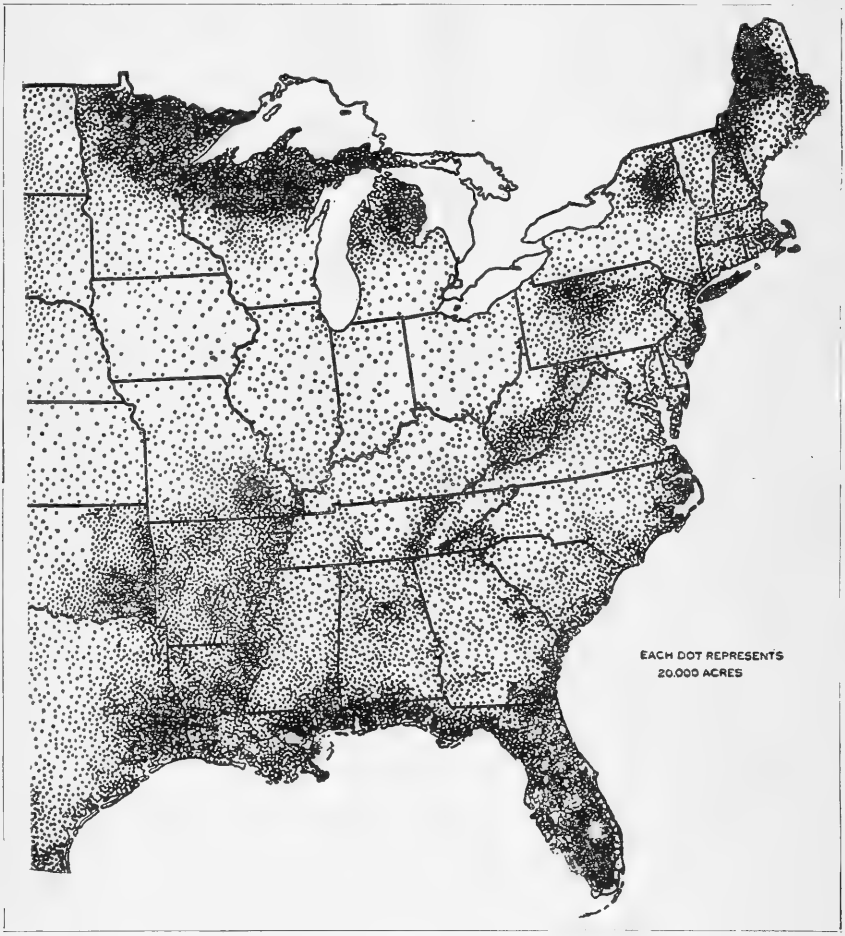

Fig. 5.—Land not in farms, according to the census of 1910.

November 11. This gives a growing season of from 220 to 240 days. The annual rainfall is heavy, seldom falling below 50 inches in any section and often reaching as high as 80 inches in some sections. Such a climate permits an abundant growth of pasture plants and offers a grazing season of 8 or 9 months.

AREA IN FARMS AND GRAZING LANDS.

Figure 5, compiled from the census of 1910, shows the land not in farms in the United States. In the States under discussion the black dots, each representing 20,000 acres, form a dark shading which follows closely the cut-over pine sections. Only 10 to 20 per cent of the section is in farms; and 80 to 90 per cent is range land, a large proportion of which has had the timber cut off. With such a small proportion of the land in farms it is evident that the production of feed must be very limited in proportion to the area of grazing.

SOILS AND TOPOGRAPHY.

The regions discussed in this report lie within the great Coastal Plain, which borders the Atlantic Ocean and the Gulf of Mexico. This plain lies to the south of the highland areas of the Piedmont Plateau and the Appalachian Mountain and Ozark regions. It rises gradually from sea level inland, attaining along the interior border an elevation of from 400 to 600 feet. Its surface is prevailingly smooth, but there is a range from the nearly level "flatwoods" along the coast to the rolling and hilly lands bordering the southern extension of the Appalachian Mountain region. The drainage varies from poor near the coast to very thorough or excessive in the more rolling portions and in the areas of deep, loose, sandy soil.

Sandy soils predominate; but there are important belts of clay land and silt loam, and many traversing streams include over their first bottoms and second bottoms strips of sandy, silty, and clay lands.

In physical composition (texture) the sandy soils are of two principal kinds, namely, sandy soils with clay or sandy clay subsoils, and deep, loose sands having no clay within 3 feet or more of the surface. The former largely predominate over the region as a whole; but there are belts, such as the Sand Hills and the Florida Flatwoods, in which deep sands occur over wide areas practically to the exclusion of soils with clay subsoils.

Near the coast the soils are light, sandy loams, with sandy subsoils. In the upland hill regions the soils become quite heavy and are subject to severe erosion if not kept covered with vegetation during winter.

The sandy soils along the coast and in the flatwoods are not well adapted to the production of forage or feed crops unless they are heavily fertilized. Drainage in the flatwoods to make them productive is usually necessary. The moist flatwoods, however, are well adapted to carpet grass and "switch" cane, and the grazing is comparatively good.

The heavier soils are better adapted to growing forage and feed crops. They are often deficient in nitrogen and phosphorus and require fertilizing, but under proper management produce good yields of feed crops and are well adapted to growing pastures. The heavier soils are in the rolling hill lands, much of which is too steep for cultivation. The topography of this land fits it particularly for grazing. In practically all sections there is bottom land and level land enough to produce a sufficient quantity of feed for wintering cattle and in many sections to grow feed for finishing cattle for market.

On the basis of topographic, soil, or drainage differences the Coastal Plain includes a number of well-defined subdivisions or subordinate regions. Detailed descriptions of the soils of the Piney Woods area, also soil-survey maps, may be obtained from the Bureau of Soils, U. S. Department of Agriculture.

SELECTION AND MANAGEMENT OF SOILS.

In the selection of a location for a cattle ranch the adaptability of the soils for growing feed and improving pastures should be an important consideration. Some locations are so rough that they must be kept in grass to prevent washing and are not suitable for cultivation. While these lands may provide excellent grazing, to be desirable they should have level or bottom lands in connection to permit the growing of winter feeds. Many locations which are adapted to cultivation so far as topography is concerned have a sandy subsoil and require heavy fertilization to produce feed crops. The fertility of these lands rapidly leaches away under cultivation, though much of the sandy land furnishes good natural grazing.

The lands which can not be converted into farming lands should be developed less intensively and in larger tracts than the more valuable tracts. Pasture improvement should be by natural rather than by intensive methods and only such feed crops grown as are necessary to carry cattle through winter and permit marketing them off grass.

The level and rolling lands with clay subsoils are well adapted for intensive pasture improvement and the production of feed crops. The fertility of these lands may be built up rapidly by the use of legumes and animal manures, and feed may be grown to fatten all the cattle produced. These lands should be converted gradually into smaller farms and their future value as such will justify the gradual improvement while being used as cattle range.

OWNERSHIP OF LANDS AND SIZE OF HOLDINGS.

This great body of undeveloped lands is now largely owned or controlled by lumber syndicates and large sawmill companies whose holdings vary from a few thousand acres to half a million. The holdings of the lumbermen who answered questionnaires on the subject averaged 29,000 acres. The owners were interested primarily in cutting off the merchantable timber and not in the future development of the lands. However, some have undertaken very creditable projects in developing their land. The lands covered with stumps, unmerchantable logs, and crowns left from logging are not attractive to buyers. The amount of land taken up by the native people as needed for farming is not extensive. Colonizing schemes have failed in most instances and the cheap land has not attracted the cattlemen. Sales of large tracts of cut-over land have frequently been made to land-sales companies whose chief interest was to make a handsome profit by resale in smaller parcels.

While the ownership of lands in large tracts has retarded development in the past, at present it is an advantage to the building of a cattle industry, as large tracts of cheap land can be bought and a wide choice can be made of lands particularly adapted to individual uses.

RECOMMENDATIONS.

Because of the newness of the cattle business along improved lines and the small number of practical demonstrations it is difficult to give recommendations based on well-established practice. There are many points, however, which should receive the attention of the present owners of these lands, beginners in the cattle business, and outsiders who are contemplating the purchase of land but who are not familiar with the region.

The immediate conversion of the great body of cut-over lands into small farms is not advisable even if it were possible. A redistribution of the ownership of the lands and their use for agricultural purposes is desirable, but the process should be gradual. The present use and development of the lands as a whole must be in large tracts consisting of several thousand acres. The lands are not improved to an extent to make them desirable as farming lands, and not until they are improved and their possibilities demonstrated will they find a ready sale at a fair price. The utilization of these nonproductive lands for reforestation and grazing purposes is the only logical solution in the near future.

Colonization has been a failure except in rare instances, and always will be so long as land is sold at high prices in small tracts to clerks, conductors, mechanics, and other city people who are allured by brilliant literature describing the possibilities of the country in an impracticable manner. The capital of such people is usually taken up by the initial purchase, and they are left without sufficient capital to develop the land sufficiently to make a living income. What the region needs is farmers with sufficient finances or backing to establish permanent homes and develop the land. The sale of unimproved land should be on easy terms, and the improvements made by the settler should furnish a satisfactory margin of security. As a matter of safety the settler should be advised as to farming methods that promise success.

The sale of small farms, except in colonies, is a slow process for the owner of large tracts, and such sales are necessarily at higher prices. From the purchaser's standpoint, small farms of from 40 to 60 acres are not large enough for a farmer to make a living. The sale of medium-sized tracts of land on reasonable terms to farmers who wish to increase their operations should be encouraged.

Lands that are not yielding enough to pay taxes at present may either be turned to raising cattle at a profit and at the same time improved so they may be marketed at a fair price as they come into demand for farming land, or be reforested, either by the present owner or by the State or the National Government.

The development of the land by the lumberman presents two phases. It may be developed with the idea of making a permanent business of farming and cattle raising, or partly developed as a demonstration of its possibilities with the idea of its future sale. In either case cattle raising must be considered as a business in itself and given intelligent and close study, the same as any other business. If the owner can not give the business this attention himself he may employ a competent manager who, preferably, should have a financial interest.

Individual farms operated for the diversion of the owner may well be show places, but ranches run for profit and demonstration farms should be as practical as possible. The profit-and-loss column of the ledger should be the principal item to show prospective buyers.

The size of a ranch for beef-cattle production in this region must necessarily be large as compared with a general farming proposition. The business must be large enough for the owner to get a living from the operations, and that requires the raising of a considerable number of cattle.

The man operating less than a section of land can not depend on cattle as the main farm enterprise without intensive pasture improvement or the use of other cattle range, as, under present conditions, 600 acres of pasture will carry but 60 head of cattle. On the other hand, the maximum size for a profitable cattle ranch is limited by the quantity of winter feed that can be produced. It must be borne in mind that the cut-over ranges do not support cattle the year round and that provision must be made for feeding cattle at least 3 months in winter. If farm labor can not be employed profitably to produce feed enough for the cattle, winter feed will have to be purchased.

Serious mistakes have been made by lumbermen who went into the cattle business on a scale out of proportion to their experience and knowledge of conditions. The most serious blunder has been to purchase large numbers of cattle and turn them loose without any provision for care or winter feed. Such mistakes have been costly and discouraging. In a great many cases lumbermen have been discouraged from entering the cattle business or have declared the business unprofitable because dividends are not quickly realized. In the production of beef cattle a large part of the profits are to be expected from the increase in the herd, and from 2 to 4 years are necessary to produce an animal for market.

As a general rule, cattle operations should begin on a small scale and be increased gradually, as the owner gains experience and is able to work out definite plans for the profitable enlargement of the business.

IMPROVEMENT OF CATTLE.

Considerable effort has been made to find a breed of cattle better suited to this region than the recognized beef breeds and larger than the native cattle. Cattle have been imported from tropical countries to cross on the native cattle or to breed pure. Undomesticated grazing animals have also been tried. Such experiments have naturally been disappointing because the object in view was to get a breed better adapted to the unfavorable conditions rather than to improve conditions themselves. It is not reasonable to expect satisfaction with any breed of cattle when half starved and covered with ticks. With the eradication of the ticks and the production of feed no other cattle will be better adapted for this region than the principal beef breeds which we already have.

The choice of a breed for this region is a matter for the individual owner to decide after his own conditions are taken into consideration. The "rustling" ability and hardiness of a breed usually is an important consideration, but the individual owner, if possible, should select the breed of cattle most generally grown in his community. The solution of the problem lies in fitting conditions to the cattle and not the cattle to conditions.

The foundation herd should be of native cows whenever possible. These are small and of inferior quality, but are also cheap. With the continued use of a pure-bred bull and judicious selection a valuable herd may be quickly built up. Quicker results may be obtained by purchasing grade cows at the beginning, but it is probable that the cheap native cows already acclimated and accustomed to the ranges will be better as a business proposition than cows brought in from other regions. Prospects for success in the Piney Woods are much more favorable for the man who grows into the cattle business than for the man who buys into it.

Pure-bred bulls of ample size and good quality and breeding should be used in every case if satisfactory improvement in the herd is expected. With money to purchase a foundation herd, it is a good policy to limit the number of cows and put the money, thus saved, into the bull. The terms "scrub bull" and "grade bull" should be synonymous from the standpoint of herd improvement, as neither has any place on the range. Although a grade bull may be a good individual he will not transmit his qualities with any degree of certainty. In other words, the prepotency which has been built up by years of breeding and selection in the pure-bred animal is lost in the grade.

Herd management in general must be such that the cattle will receive plenty of feed and reasonable care. Pastures must be provided so that bulls and heifers can be separated to prevent breeding of immature animals. Heifers should not be bred until they are of sufficient size not to be retarded in growth, or until they are about 18 months old. Calves should be weaned when they are old enough to take care of themselves and not allowed to continue sucking the dams, as is now generally practiced. If calves are weaned at the proper time the cows will breed more regularly and drop stronger calves. One bull should be kept for every 25 cows on the range, to insure a maximum calf crop.

In the Piney Woods section cows may be safely bred to drop calves in February or March and have 1 or 2 months' advantage over range calves of any other section of the country. Only when plenty of feed can be supplied throughout the winter should cows be bred to drop fall and winter calves.

The native cattle are not regularly supplied with salt and many of them have to learn to lick it. Salt is an important element and should be supplied to cattle regularly.

Methods of management depend on local conditions and must be worked out for individual cases. A definite system for growing, feeding, and marketing cattle should be outlined by each owner and followed consistently.

PASTURES.[1]

The South is frequently, though erroneously, referred to as "a land of no grass." This impression arises from the fact that for generations the cotton farmer has been taught to fight grass as a deadly enemy. His aversion to grass has been responsible in no small measure for the slow development of the cattle industry.

The commercial production of beef cattle on an extensive scale must be founded on the use of cheap pastures and forage crops, and

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[1] The material in this bulletin relative to forage plants is prepared in accordance with the advice of the Office of Forage Crop Investigations of the Bureau of Plant Industry.

the importance of beef-cattle production should be in direct proportion to the amount of grazing furnished. The abundance and quality of the native pastures, therefore, are points of prime importance in considering the cut-over lands for beef-cattle production.

Though the Piney Woods region is not noted for the general use of tame or cultivated grasses, the growth of native vegetation is abundant in all sections, and in most places could be termed luxuriant.

NATIVE PASTURES.

The term "native pasture," as used in this bulletin, refers to the open range as left after logging operations. Such range is unfenced and covered with stumps, crowns, unmerchantable logs, and small timber. Practically no undergrowth is present immediately after the land is cut over, but a second growth of blackjack oak, scrub oak, or pine saplings appears in a few years, depending upon the kind of soil. Grazing is scarce in the virgin timber, as the ground is heavily shaded, covered with a carpet of pine needles, and burned over each year. With the removal of the timber grass becomes more abundant.

The principal native pasture grasses are wire grass,[1] broom sedge, carpet grass, lespedeza or Japan clover, "switch" or reed cane, maiden or blue cane, hop clover, and Bermuda grass.

In general the grasses of the native pastures consist almost entirely of wire grass and broom sedge, the important additions being carpet grass and lespedeza, which are not abundant except in pastures protected from fire. The native pastures furnish good grazing from early in spring until about the first of July, and the carrying capacity is relatively high. About that time wire grass and broom sedge begin to mature and the grazing is inferior, only the growing tender portions being eaten by cattle. Grazing changes largely to the Paspalums and lespedeza, and cattle require practically unlimited range to maintain themselves.

Although there is usually an abundance of dead wire grass left on the range during fall and winter, it serves only as a filler and cattle will not eat it if any other forage is available. Winter pasture consists almost entirely of canebrakes and some carpet grass, both of which are usually very limited.

Wire grass[1] constitutes the principal growth of the native pastures, and the Piney Woods is often referred to as the "wire-grass country." Wire grass furnishes good grazing in the growing season of early spring, and cattle make good gains during this season, but do not like it when the stems become hard and dry with mature growth.

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[1] The term "wire grass" includes a great many species of Aristida besides some of Sporobolus and Muhlenbergia. Small, in his Flora of the Southwestern United States, describes 28 species of Aristida.

Broom sedge is a coarse grass commonly considered a weed, which takes possession of old fields and waste places throughout the entire Piney Woods. It furnishes fairly good grazing early in spring, but is not relished by cattle as it approaches maturity.

Carpet grass (*Axonopus compressus*), is strictly a pasture grass, growing to a height of only a few inches, and is seldom if ever cut for hay. It prefers moist, sandy lands, but is not confined to lowlands, as good stands are found on the rolling and hill lands. It will stand closer grazing and heavier trampling than any of the other pasture grasses, solid stands of it occurring only where it is closely grazed. Farmers' Bulletins 1125 and 1130 treat this grass in detail.

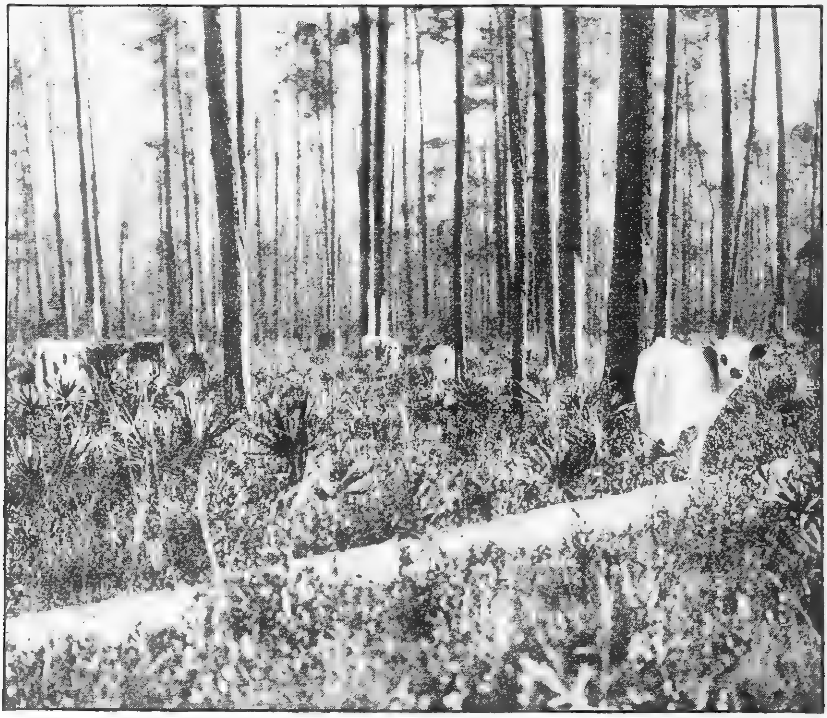

FIG. 6.—Native cattle grazing typical flatwoods range pasture in December.

Lespedeza or *Japan clover* is well distributed throughout the Piney Woods. It has shown an adaptation to cut-over lands surpassed by no other pasture plant in its ability both to spread rapidly and to flourish on a wide variety of soils. Detailed information regarding lespedeza will be found in Farmers' Bulletins 441 and 1125.

Switch or reed cane, *maiden cane*, *blue cane*, and *hop clover* are of minor value at present as forage plants. (See Farmers' Bulletin 1125.)

Bermuda grass is not found extensively in native pastures, except in a few favored spots where it has been transplanted. It is important only on cultivated land. (See Farmers' Bulletin 1125.)

CARRYING CAPACITY OF NATIVE PASTURES.

No experimental data are available as to the carrying capacity of the native pastures, but from observation and hundreds of inquiries it appears that 10 acres per head for 8 or 9 months in the year is a fair average. Cattle, as a rule, have unlimited pasture, and where the pasture is limited it is under fence and usually has been improved to some extent.

Questionnaires were mailed to every owner of a pure-bred beef bull in the Piney Woods, so far as lists were available, and answers to the question, "How many acres necessary to carry a cow on cut-over pasture?" varied from 4 to 20 acres, with an average of 8.3. Most of the answers of men grazing a considerable number of cattle were "Ten acres or more." Cattlemen of long experience in grazing cut-over lands, without exception give that number as the minimum for unimproved pasture during a grazing season of 8 or 9 months. During spring and the early part of summer the carrying capacity is probably 5 acres or less per head, but provision must be made for the inferior grazing after wire grass and broom sedge mature. Ten acres per head seems high for a humid region where vegetative growth is rapid, but is much lower than that required on western ranges and may be reduced considerably under proper management.

RANGE FIRES.

The native pastures have been almost universally burned over each year ever since the country was settled in Florida for fully 150 years, and especially since the time turpentine operations began in the virgin timber, long before the Civil War. In timber tapped for turpentine the face and base of the tree are saturated with resin and the box which catches the resin flow is within easy reach of ground fires. To protect the trees against accidental and pasture fires, the trash is raked away from the bases of the trees and the woods burned under watch each year, the carpet of pine straw and dead grass furnishing fuel. This practice makes it easier for the workmen to cover the ground as the underbrush is burned off.

During logging operations no precaution is taken to prevent fires from locomotives, and where the woods are not fired from this source the woods crew burn the undergrowth to make walking easier.

After the turpentine operator and the lumberman, the native cattle owners perpetuate the annual burning of the range. Cattlemen for generations have practiced burning the ranges in the winter or early spring because it makes earlier spring grazing. As a matter of fact, the grazing on burnt-over ranges is no earlier and may be considerably retarded. It should be done before the spring growth starts and not oftener than every three years, especially on heavily grazed pastures. Where a heavy growth of dead grass remains on the range during winter it affords considerable protection to the tender, grow-

Fig. 7.—Native cattle grazing on open range which has been burned over. Compare the grass with that on range protected from fire, shown in figure 6.

ing parts underneath, so that some growth will be made even during winter. If the dead grass is burned in spring this protection is removed and much of the early growth that might be picked out by cattle is destroyed. Cattle prefer the burned pastures early in spring because of the ease of grazing, as they do not have to pick out the green from the dead grass and are able to get a quicker fill; but the carrying capacity of burnt range is no doubt lowered to a considerable degree by the injury done to growing plants.

Burning the range year after year for so long a period has been injurious to the pastures to an extent difficult to estimate. Perhaps the most serious injury by fire has been the destruction of vegetation before the organic matter could become incorporated with the soil to form humus, in which the soils of practically all that region are deficient. On clay lands continually burned over, the soil is often devoid of humus to such an extent that pastures will "checkcrack" in very dry weather and present much the appearance of the checks in a dried mud puddle. The quantity of organic matter in a single season's growth on cut-over land is very great, and when it is considered that practically all of it is consumed by fires the total loss of valuable fertilizer can readily be appreciated. On land used for farming purposes this annual destruction of organic matter means a heavy loss in crop production and the additional use of commercial fertilizer, which in itself is a poor substitute for a supply of humus.

Another effect of frequent fires on native pasture has been to keep out the desirable pasture grasses and perpetuate the undesirable ones. Wire grass and broom sedge have been able to withstand fires to such an extent that they have almost taken possession of the cut-over lands. These plants, although furnishing most of the grazing, are undesirable because of their short grazing season, and are no better adapted, except in their ability to withstand fire, than carpet grass and lespedeza, the two most valuable pasture plants found on the range.

The reason for the ability of wire grass to withstand fire and not close grazing is not altogether apparent, but it is largely accounted for by the habit of growth and the season of growth. The grass is perennial, firmly rooted, and grows in clumps, the stools of which protect the growing parts from fire to some extent. The plant matures early in the season and the fuel for fires in the fall is largely the dead stems and leaves of these plants. Thus it may be seen that fall fires come at a time when the plant has seeded and the season's growth is completed, while the spring fires do not affect the stools of the perennial plant as they do seedlings of annual plants and more tender perennials.

Although carpet grass is a perennial that stands close grazing, it is very susceptible to fire. The seed is matured late in the fall, and the plant is still growing at the time of fall fires. In the spring the tender, creeping stalks are not protected to the same degree as are the clumps of wire grass and broom sedge.

Lespedeza is seriously checked by fires because it is an annual which seeds late in fall at a time when fires are most likely to occur. Unshattered seeds are all destroyed and most of the seeds already dropped are destroyed, as they are loose and unprotected as compared with later in the season after beating rains have covered them with soil. The seeds are contained in a chaffy hull which burns readily. Spring fires come at a time when the seeds are germinating, or when the young plants are too tender to withstand fire.

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Without the destructive annual fires the soils of the cut-over lands and the distribution of grasses would have presented a different aspect; and since the damage done is apparent, immediate steps should be taken to prevent fires. However, occasional fires under proper control may be used to remove accumulations of wire grass and to check the growth of brush.

SEMI-IMPROVED PASTURES.

For convenience of discussion in this report, stump land which has been fenced, cleared of underbrush or down timber, and protected from fire, is spoken of as semi-improved pasture, since these are the first steps for pasture improvement in the logical order in which they should come for natural improvement of the range. Very little work toward improving pastures has been done until the last few years. Owners of large tracts of land who have started in the cattle business have begun some pasture-improvement work, but, except in very few instances, they have not made progress enough to demonstrate its final value. On cut-over land, stumps ranging from 10 inches to 2 feet in diameter average about 50 to the acre, and these stumps, together with the crowns and unmerchantable timber left after logging operations, occupy much space on which no grass can grow. Land not closely grazed immediately after the removal of the timber is quickly taken up by a second growth of blackjack oak, scrub oak, and pine saplings, which shade the ground and also occupy considerable space.

The cost of removing stumps is prohibitive for cheap pasture on large areas, but "down" timber is cleared from the land by piling and burning or by marketing as firewood in near-by towns. Second-growth timber is removed by cutting with axes, but the oaks sprout immediately and require recutting the second or third year. In some cases goats and sheep have been used successfully in checking the growth of sprouts. Land fenced and cleared of down timber and second growth is usually protected from fire by burning around the edges or by keeping watch for fires and extinguishing them.

These methods effect an immediate improvement in the pastures by reducing waste space and shade. In addition, volunteer lespedeza and carpet grass make their appearance and improve the pasture rapidly. Confining the cattle by fencing means closer grazing, and with close grazing and trampling wire grass and broom sedge are checked and carpet grass and lespedeza take their places. Rapid improvement in the carrying capacity and quality of the pastures has been observed in many places on limited areas when these methods were used, and the improvement of the pastures, especially by protection from fire, shows great future promise.

Semi-improved pasture in Covington County, Miss., protected from fire was closely observed for 2 years. During that time the stand of lespedeza was estimated to have increased 75 per cent. It was thoroughly distributed throughout the pastures and constituted from a third to half a stand. Carpet grass also increased to an appreciable extent. No seed of either plant was ever sown on these pastures.

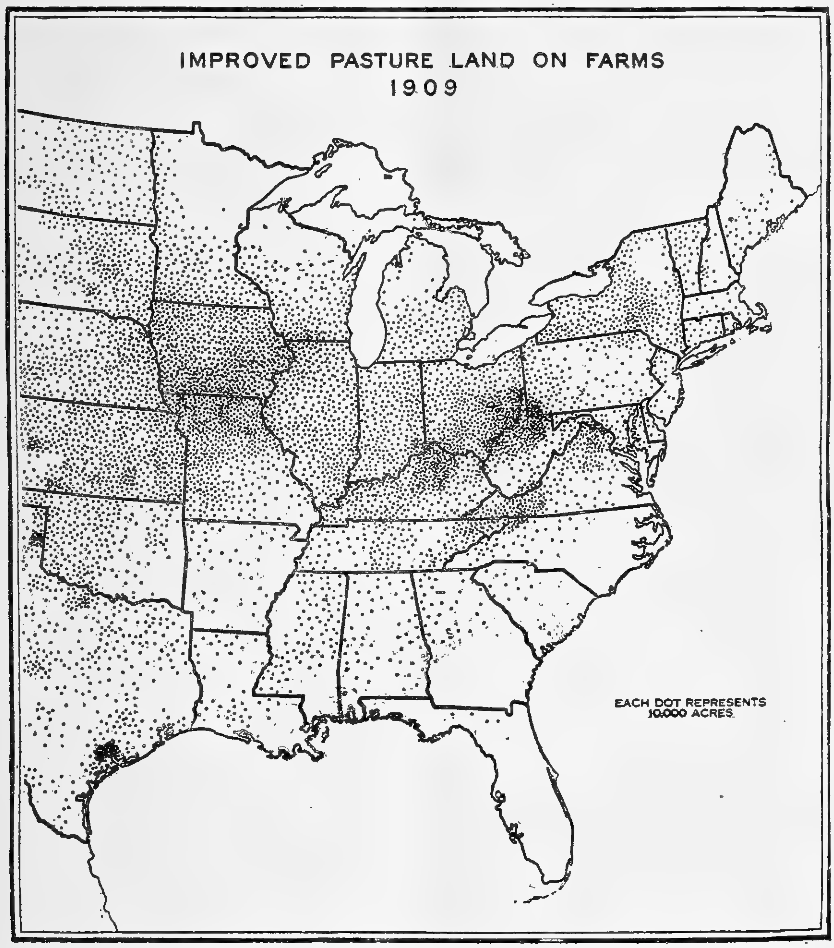

Fig. 8.—Improved pasture land on farms. Compare the improved pasture lands of the Coastal Plain with that of the cattle-producing section of the Middle West.

Similar instances were mentioned by a large number of men in answering the questionnaires sent out.

Land fenced and cleared to some extent facilitates seeding to carpet grass and lespedeza without cultivation, but very little information is available as to results by any other method than natural seeding.

IMPROVED PASTURE.

Improved pasture as referred to in this report is defined as pasture which is fenced, protected from fire, and seeded to some pasture grass. Practically all such pasture is on cultivated land which has been cleared of stumps and is under cultivation. Bermuda grass is the foundation of practically all improved pastures in the Piney Woods.

At Collins, Miss.,[1] excellent stands of lespedeza and Bermuda were obtained on native pastures which were disked and the seed sown broadcast at the rate of 15 pounds of lespedeza and 3 pounds of Bermuda per acre.

At the McNeill station, in southern Mississippi, E. B. Ferris reports success through sowing 2 pounds of Bermuda-grass seed to the acre, mixed with 100 pounds of fertilizer, on rough land cleared only sufficiently to get a " scooter " plow through it to break it up in patches here and there. The land was sufficiently sodded to make good pasture after midsummer of the first year. Later the Bermuda grass was crowded out by carpet grass. However, Mr. Ferris adds:

> Many of the best pasture crops do not thrive as they should on the wild lands until the lands have been plowed and sweetened—at least to a limited extent. To plow and mow these lands with stumps still on them is almost out of the question.[2]

Good results have been observed in a few instances where lespedeza and carpet grass had been sown on rough stump land, disked or roughly broken with plows. Lespedeza and carpet grass show particular promise for seeding on stump land, as they are especially adapted and come in naturally on such land. Carpet-grass seed is now a commercial product. Stands may also be obtained by protecting patches of carpet grass from grazing, cutting the hay, and scattering it over the ground to be seeded.

In the improvement of native pastures many varieties of forage plants are useful. Among these are Bermuda and carpet grass, already referred to, which are recommended as a foundation for permanent pasture. Good results can not be expected from any of the northern pasture grasses, a possible exception being white clover. Alfalfa is not adapted to the Piney Woods section. Many imported grasses, such as Para grass, Rhodes grass, Guinea grass, St. Augustine grass, Natal grass, and Napier grass, have been tried and found important in some sections, but are limited to the coast line and the peninsula of Florida because of injury by frost. Information as to these grasses can be found in Farmers' Bulletin 1125.

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[1] The work at Collins, Miss., was conducted by the Bureau of Animal Industry, U. S. Department of Agriculture, in cooperation with the Mississippi Agricultural and Mechanical College, on the ranch of H. M. McIntosh, and was continued for 2 years.

[2] Mississippi Bulletin 180.

TEMPORARY PASTURES.

Temporary pastures include winter-grazing crops or cover crops and volunteer or unseeded crops on cultivated lands. Winter-grazing crops consist of the small grains, such as oats and rye, and winter-growing annual legumes, such as bur clover, crimson clover, and vetch. The most important volunteer pasture crops are crab grass, Mexican clover, and beggarweed.

Winter oats of a rust-proof variety sown early in fall are used for winter grazing. Oats can be grazed slightly in the fall and winter, but as the oats are usually grown for the grain crop, heavy grazing is questionable. (Farmers' Bulletin 436.)

FIG. 9.—Cattle grazing Abruzzi rye in February on the beef-cattle experiment farm at Collins, Miss. This pasture was grazed from the latter part of November until the last of March.

Hairy or *sand vetch* is frequently sown with oats for winter grazing. The addition of vetch greatly increases the winter grazing and the cattle may be removed in the spring and the oats and vetch cut for hay. (Additional information concerning vetch in southern sections is contained in Farmers' Bulletins 515 and 529.)

Rye, especially the Abruzzi variety, which was introduced by the United States Department of Agriculture from Italy, has proved to be far superior to oats for winter grazing. At Collins, Miss., in the fall of 1917, Abruzzi rye and oats were sown the same day on equal parts of a field and under exactly the same conditions. The rye made good growth and furnished excellent grazing through winter and early spring, and after pasturing was cut for grain. Scarcely a single spear of oats survived the severe winter and furnished no grazing whatever. (Detailed information concerning rye is contained in Farmers' Bulletin 894.)

Crimson clover is an annual winter-growing legume grown to some extent in the Piney Woods for pasture and hay. Crimson clover furnishes very little fall or winter grazing, but is important for 6 weeks in the early spring between rye and other pasture. (Crimson clover is fully discussed in Farmers' Bulletins 550, 579, and 1125.)

Crab grass is the most common volunteer grass after cultivated crops. It comes in thickly after early corn has been laid by, and if the corn is removed makes considerable grazing through September and October. (See Farmers' Bulletin 1125.)

Mexican clover, also called "Florida pusley," is not a true clover or legume, but is a summer annual belonging to the madder family, which makes a rank growth resembling red clover. It is a common volunteer crop after early corn in most sections of the Piney Woods and makes a heavy growth each year when once established. After removal of the corn it makes fairly good grazing until heavy frost and makes a fair quality of hay and is often cut for that purpose. Its value as a cover crop, as late fall grazing, or as a hay crop, should entitle it to some consideration. The seed is not sold commercially, but may be obtained from lofts where the hay is stored, and is sown in the spring at the rate of 5 or 6 pounds per acre.

Beggarweed, an annual legume growing erect and reaching a height of from 4 to 8 feet, is a common volunteer crop through all sections of the Piney Woods, but makes its best growth in Florida. It has a high feeding value and makes excellent grazing until some time after frost. It is often cut for hay and is relished by cattle, although it is usually coarse. Seed is easily collected and may be sown at a small cost where the plant is not already well established. (See Farmers' Bulletin 1125.)

PERMANENT PASTURES.

Permanent pastures of exceptionally high carrying capacity and long grazing period can easily be established and maintained on lands cleared of stumps and under cultivation. These pastures supplemented with temporary pastures for winter grazing enable the farmer to graze his cattle throughout practically the entire year.

Included in the questionnaire sent to pure-bred breeders was the question: "How many acres are necessary to carry a cow on improved pasture?" The answers to this question varied from one-quarter of an acre to 3 acres, with the majority giving 1 acre per head. The average of all answers was 1.6 acres per head for the grazing season. Fifty-seven per cent of these men reported no improved pasture. The foundation of practically all these pastures was Bermuda grass, although a large number included lespedeza and a few were carpet-grass pastures. That the average of 1.6 acres per head is a conservative figure for improved pastures is borne out by the writers' observations in all sections. Many pastures have been observed which had a considerably higher carrying capacity, and as a rule the Bermuda and carpet-grass pastures are understocked rather than overstocked during the season of most rapid growth. Both Bermuda and carpet grass will stand very close grazing, and Bermuda especially is not relished by cattle if it is allowed to make a rank growth.

The general farmer or small landowner should spare no effort in establishing pastures on cleared lands in order that the small number of cattle he is able to keep may have the most favorable grazing. The large landowner or ranchman with many cattle can establish pastures on cleared land only gradually and in a limited way. He is concerned with utilizing the cheap range pasture and his problem is improving large areas of the native pasture with the stumps on. Cost is the limiting factor in improving large areas and the problem is necessarily more difficult in its solution. The native pastures can not be improved immediately to have the carrying capacity of the permanent pastures described above without clearing the land. They may be gradually improved, however, at a very small cost, so that their carrying capacity will be doubled.

Considerable selection can be made from the great number of pasture and forage crops grown in the Piney Woods section, but certain crops have become prominent in different regions. The recommendations for the Coastal Plain as given by the authorities of the different experiment stations is tabulated below, including the three important pasture and hay plants of each State. Many other crops which do well are not included. The recommendations were given by Director H. W. Barre, of South Carolina; Prof. J. R. Fain, of Georgia; Director P. H. Rolfs, of Florida; Director J. F. Duggar, of Alabama; Director of Stations J. R. Ricks, of Mississippi; Dean W. R. Dodson, of Louisiana; Director of Extension W. C. Lassetter, of Arkansas, and Prof. A. B. Conner, of Texas.

TABLE 3.—*Pasture and hay crops for the Coastal Plain.*

Station.	Pasture.	Hay.
South Carolina (Barre)	Bermuda, carpet grass, lespedeza	Cowpeas, velvet beans, sorghum.
Georgia (Fain)	Carpet grass, Dallas grass, Rhodes grass	Cowpeas, sorghum, beggarweed.
Florida (Rolfs)	Bermuda, carpet grass, Para grass	Crab grass, cowpeas, beggarweed.
Alabama (Duggar)	Bermuda, lespedeza, bur clover	Cowpeas, sorghum, lespedeza.
Mississippi (Ricks)	Carpet grass, lespedeza, Bermuda	Lespedeza, cowpeas, Sudan grass.
Louisiana (Dodson)	do	Cowpeas, lespedeza, sorghum.
Arkansas (Lassetter)	Bermuda, carpet grass, lespedeza	Cowpeas, soy beans, sorghum.
Eastern Texas (Conner)	Bermuda, lespedeza, bur clover	Cowpeas, Sudan grass, sorghum.

RECOMMENDATIONS.

The improvement of the native pastures is the most important problem of beef-cattle production in the Piney Woods. Although there is an abundance of grass on the range it furnishes good grazing for a short period only and the native grasses must be replaced to a considerable extent by more desirable plants before the pastures will have a high carrying capacity. A system of management must be devised to bring about the gradual replacement of the native grasses by facilitating the spread and natural reseeding of more desirable forage plants.

Two very important forage plants, carpet grass and lespedeza, have established themselves in practically every county of the Piney Woods; and, while it is not advisable to discontinue the trial of other pasture plants, every effort should be made to protect and facilitate the spread of these two. At present there are no other plants known which are so desirable and so well adapted to this region. The worst enemy to the spread of carpet grass and lespedeza is fire. With fencing, fire protection, removal of undesirable underbrush, and proper stocking the natural spread of these two plants is rapid. Every practical effort should also be made to protect the growth of young pine on land not suited to cultivation.

Fencing and fire control are the first two steps toward pasture development. A fence establishes ownership and property lines, keeps out scrub bulls and other cattle, aids in establishing fire controls, and confines cattle to a definite area. The ranges deteriorate rather than improve so long as fire runs over them annually. The advantage of fire protection from the standpoint of increasing the fertility of the soil and protecting desirable pasture plants is beyond question and has been repeatedly demonstrated by individual owners.

For the individual owner to prevent fires on his pasture when the surrounding range is fired is a difficult matter, but it can be accomplished by constant watch, burning around the pasture, or plowing a strip wide enough to stop fire. Prevention of fires is the most logical method, but it can not be done until cattle owners and land owners realize the destruction done. Accidental fires may be prevented by precaution, but so long as the belief prevails that the grazing of cattle is improved by annual burning of the range, set fires will run over the range each year. Concerted action should be taken by cattlemen and the owners of range land to start an educational campaign against fires and procure suitable legislation for their prevention.

If the land is to be used exclusively and permanently as pasture, second-growth oaks should be kept down, because they will shade pasture plants and occupy considerable space. Underbrush may be cut but will quickly sprout and require recutting in the course of 2 or 3 years. If closely grazed by sheep or goats the sprouts may be killed. An arsenic poison has been successfully used for killing all kinds of timber and effectually preventing sprouts. Trees are killed in a few weeks' time and often in a few days by deep girdling and applying a solution made according to the following formula:

White arsenic (arsenic trioxid)	1 pound.
Washing soda	1 pound or
Caustic soda	½ pound.
Whiting	½ pound.
Water	4 gallons.

Dissolve the soda in water, using heat if necessary; then slowly add the arsenic, previously made into a thin paste, stirring all the time; place on a strong fire and boil for half an hour, stirring from time to time. When the arsenic is thoroughly dissolved add the remainder of the water to make up the 4 gallons. The whiting shows the trees treated, as it turns white on drying. Trees are girdled by a heavy downward stroke of the axe cutting through the bark and well into the wood. From a half-pint for small trees to a quart for large ones is applied to saturate the girdle. Saplings may be cut off low and the poison thoroughly applied with a swab. The poison is more effective if applied in winter or early in spring, but will kill trees at any time.

Down timber should be removed for firewood or piled and burned, as it occupies space on which no grass can grow. The removal of underbrush and down timber increases to a considerable extent the carrying capacity of pastures.

Seeding the native pastures, following the removal of second-growth and down timber, will facilitate the rapid replacement of the native grasses. Lespedeza and carpet grass may be sown on favored spots of unprepared ground to hasten their natural spread, or where the land is sufficiently clear it may be disked at little cost before seeding. Disking also helps kill out the wire grass. The beds of old tramroads from which the ties have been removed furnish seed beds where desirable grasses may be established and gradually spread over the pasture.

Stocking the pastures heavily gradually kills out wire grass and establishes carpet grass, but where pasture is grazed close enough in spring to kill wire grass other pasture must be provided during summer and fall, as the cattle will suffer if not given wider range when the pasture begins to fail. Wire grass and broom sedge must be grazed closely to be fully utilized, as cattle do not eat it readily after it matures. The pasture will gradually improve if closely grazed and protected from fire at the same time, but should be seeded to lespedeza and carpet grass for rapid improvement.

Where some improved pasture is available, the native pasture may be grazed closely in the early part of the season, gradually removing the cattle to the improved pasture. This method allows the improved pasture to get a good start while the native pasture is being used to the fullest advantage.

Improved pasture on cultivated land should be established gradually for permanent pasture whenever possible, especially by the small farmers who have limited pasture. Bermuda is recommended on rich ground or ground to which manure has been applied, but should always have lespedeza and bur or white clover added. Carpet grass is much better adapted for the foundation of pastures on sandy lands and should be sown with Bermuda whenever the seed can be obtained. Lespedeza should be sown with carpet grass.

Abruzzi rye, especially if vetch or bur clover is sown on the same field, is recommended above any other crop for winter grazing.

WINTER FEEDS.

The saving of the dry roughage, such as corn stover, and the making of hay are rendered somewhat difficult in the Piney Woods section because of the frequent rains at seasons when the crops mature and the moist atmosphere, which is favorable to the growth of molds on forage when left in the field, especially corn stover in shocks.

Corn stover may be cured and fed from the field in favorable seasons, but it is usually necessary to rick it with some protection from the weather or store it under cover. The common method of utilizing corn stover is to pasture the stalk fields in the fall after the corn has been snapped, especially since velvet beans are now commonly planted in all corn, and the vine growth makes the cutting of stover very difficult. When properly saved, corn stover is a very valuable roughage for winter feed, but if left in the field a considerable portion of the forage is trampled down, damaged by rains, or blown away, and much of the feeding value is lost.

Lespedeza is gaining favor rapidly as a hay crop. It has been very successfully grown for hay on the heavier soils, especially when supplied with some phosphate fertilizer. It contains little water and is the easiest of all legumes to cure into hay. When grown in dense stands it is very heavy in weight because of the fine, solid stems, and even when only 6 to 8 inches high and apparently hardly worth cutting for hay it will yield a ton or more per acre. The hay is of excellent quality, is relished by cattle, and is equal in feeding value to alfalfa hay. When the seed is sown in February or March on oat land it will make a crop of hay the first season after the oats are harvested. The plants, if allowed to mature, will reseed the land indefinitely. After the lespedeza is removed the land may be again sown in oats. Ferris, at the McNeill station, Miss., reports the best yields of oats by using this method, and obtained 2 tons of lespedeza hay following the oats.[1] No other hay crop in that section is more valuable as a feed. It can be grown with less trouble and expense than any other hay crop and at the same time it improves the land for future crops. (This subject is discussed in Farmers' Bulletin 441.)

The cowpea is the most common cultivated crop grown for hay in the Piney Woods section. This crop commonly follows oats and is sown broadcast for hay, as it smothers weeds and crab grass. (Detailed information concerning cowpeas is contained in Farmers' Bulletins 318, 1125, and 1153.)

The soy bean is an annual legume similar to the cowpea but is not so extensively used. It makes a heavier growth of seed than the cowpea, but when sown broadcast cowpeas make a heavier yield, as well as smothering the weeds. (Soy beans are discussed in detail in Farmers' Bulletins 931, 973, and 1125.)

Peanut hay is rapidly coming into use in some sections of the Piney Woods, especially in Alabama and Georgia, and is now put on the market as a commercial hay. Peanuts are grown as a forage crop after the removal of oats or rye and the tops mowed for hay the same as cowpeas or other legumes, leaving the nuts in the ground to be harvested by hogs. The yield of hay is between 1 and 2 tons an acre. Peanut hay is coarse but of good quality, is relished by cattle, and has a feeding value equal to clover hay. (Methods of growing and handling the crop are fully discussed in Farmers' Bulletins 431 and 1125.)

Table 4 gives the analyses of lespedeza, cowpea, and peanut-vine hay as compared with alfalfa hay.

TABLE 4.—*Analyses of three southern legume hays compared with alfalfa hay.*[1]

Kind of hay.	Number of analyses.	Constituents.					
		Water.	Ash.	Crude protein.	Carbohydrates.		Fat.
					Crude fiber.	Nitrogen free extract.	
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Alfalfa	250	8.6	8.6	14.9	28.3	37.3	2.3
Lespedeza	14	11.8	5.8	12.1	25.9	41.6	2.8
Cowpea	35	14.8	7.3	16.5	20.4	37.3	3.7
Peanut vine	7	21.5	8.7	9.1	20.2	36.8	3.7

[1] Analyses from Henry and Morrison.

Table 4 shows lespedeza hay to be practically equal to alfalfa hay. It is slightly lower in crude-protein content, but is also lower in

[1] Mississippi Bulletin 180.

fiber content and higher in fat. Cowpea is higher in crude-protein content than alfalfa, lower in fiber, and higher in fat. Peanut hay is not equal to these hays in crude-protein content, but is low in fiber and high in fat.

Sudan grass is frequently sown in mixtures with cowpeas or soy beans for hay and facilitates the curing of the hay. At the McNeill station, in Mississippi, Sudan grass, planted in drills 3 feet apart about the middle of May, gave two cuttings totaling 4 tons of hay. With the exception of lespedeza, which it exceeded in yield, it was superior to any other hay tried at the station. (Detailed discussion of Sudan grass may be found in Farmers' Bulletins 605, 1125, and 1126.)

Sorghum is sown broadcast and cut for hay to some extent in the section described. It is a good yielder, but the large, juicy stems make it difficult to cure and it is more valuable and more easily handled as a silage crop. (See Farmers' Bulletin 1158.)

Crab grass, *Mexican clover*, and *beggarweed* are volunteer crops which are important for hay, as they cost nothing except to harvest.

Crimson clover is grown to a limited extent as a hay crop. The hay is of good quality and is relished by cattle. Other crops seem to be better adapted as hay crops.

Hairy or *sand vetch* is planted in the fall with oats or rye and the crop is grazed during winter and early spring, yet it makes a heavy yield of hay after the removal of the cattle. (See p. 29.)

Cottonseed hulls is a commercial feed obtained as a by-product of the manufacture of cottonseed oil. It has been extensively used as a roughage and is about equal to corn silage, but is much more expensive and is being replaced by cheaper home-grown roughages.

The velvet bean (Farmers' Bulletins 962 and 1125), an annual leguminous, twining vine, is now grown in the Piney Woods more extensively than any other crop except corn, with which it is almost always planted. The velvet bean was grown first in Florida and has been cultivated extensively only in recent years. In 10 years, however, the acreage has grown from an insignificant figure to a point where practically every acre of corn in the Piney Woods is now planted to velvet beans, the most important forage and feed crop grown there.[1]

At the present time cornstalk and velvet-bean pasture is the principal winter-forage crop of the Piney Woods both for maintaining cattle through the winter and for fattening them. The practice of pasturing cattle on velvet-bean fields has become such an important factor in wintering cattle that most farmers provide no other

[1] Farm practices that increase crop yields in the Gulf-coast region are discussed in Farmers' Bulletin 986.

winter feed. The cattle are held on the native pastures until the pastures give out and are then put on velvet-bean fields to hold them until grass comes in the spring.

After the corn is harvested the beans are usually partly picked if the cattle are to be carried through the winter on a maintenance ration, but if cattle are to be fattened they are turned on fields from which no beans have been picked. The leaves remain on the vines for a considerable time and are eaten better by cattle after frost comes. The beans remain in the field about three months during the winter without shattering or damage from rains. In fact, after they have been softened by rains the cattle like them better. Beans which are trampled to the ground are utilized by following the cattle with hogs. The carrying capacity of the pasture varies considerably according to the yield of beans per acre, but it is usual

FIG. 10.—Corn and velvet beans. Velvet beans make an excellent growth along with the corn.

to allow from one-third to one-half an acre per head per month. It requires from 1 to 1½ acres to carry a cow through the winter.

At Collins 56 head of mature breeding cows and 22 head of mature native steers were turned on 40 acres of velvet-bean pasture December 3, 1917. The pasture consisted of stalk fields from which the corn had been snapped and velvet beans left unpicked. Ten acres of this field would have yielded 1,000 pounds or more of picked beans per acre, but the beans on the remainder of the field were scattering. The average yield of the entire field was estimated at 500 pounds an acre. The pasture was practically exhausted at the end of a 28-day period and hogs were left to clean up the remaining beans. Pasture was furnished at the rate of one-half acre per head per month and the breeding cows made an average daily gain of 1.25 pounds a head.

Stock cattle are sometimes given limited pasture on bean fields from which no beans have been picked. By this method the cattle are turned on the field for an hour or more each day and then taken off. This lengthens the grazing period and is an economical way to handle the crop if cattle are not to be fattened. If steers are to be fattened for market they are often allowed the run of a bean field until the best of the beans are consumed, then removed to a new field, and the stock cattle turned on the old field to clean up what is left.

The sandy soils of the Piney Woods region are not injured by pasturing cattle while the ground is wet during winter, and where velvet beans are utilized in this way considerable labor is saved and the fertility contained in the crop is left on the ground, adding greatly to the value of the crop as a soil improver. Since the beans will keep in the field until consumed and few beans are lost, it would appear that the only advantage in harvesting the beans for feed is in controlling the quantity of beans consumed. However, there are several serious objections to pasturing the beans as now practiced. These points are discussed under "Recommendations for winter feeding."

It is worthy of particular note that nearly all the important forage crops of the section are legumes. Besides the high feeding value due to the protein content, the legumes have a high content of lime, which is a very necessary element in the growth of animals. Timothy hay has 2.5 pounds of lime per 1,000 pounds, while cowpea hay has 25.4 pounds.[1] The soils of this region are naturally deficient in lime and the increased use of legumes, especially for young growing animals, should be highly beneficial.

CONCENTRATED FEEDS.

The velvet bean is the principal concentrated feed now used for feeding cattle in the Piney Woods and with the increasing acreage grown each year it is rapidly replacing all other concentrated feeds both for fattening and wintering cattle. Aside from its recognized value as a feed it is a home-grown crop which is more readily marketed through cattle than in any other way. The increased use of velvet beans has permitted the shipment of larger quantities of cottonseed meal to other sections of the country, as the meal is a more concentrated feed for which there is a well-established market. In some localities since 1915 the production has greatly exceeded the amount needed for home consumption and mills have been established

[1] From Henry and Morrison.

for drying and grinding the beans into a commercial feed. For home consumption the beans are usually fed in the pod, as they are difficult to grind, quickly become rancid, and the feeding value is not increased by grinding.

That the velvet bean is a very valuable concentrated feed for cattle has been thoroughly demonstrated. Feeding tests have shown that about 2 pounds in the pod are equal to 1 pound of cottonseed meal and in addition the roughage required is lessened because of the dry matter in the bulky pods. The high feeding value of velvet beans in the field is beyond question and it is now a common practice to market fat steers directly off the bean fields in February and March. Though these steers do not have the high finish of steers fed during a longer period they sell for a good price. The practice of fattening cattle on velvet-bean pasture is an economical one, because few beans are wasted, little labor is required, and the fertilizing value of the crop is retained on the land.

The Bureau of Animal Industry, United States Department of Agriculture, with the cooperation of the Mississippi experiment station, conducted an experiment at Collins, Miss., during the early part of 1918, to determine the economy of a ration of velvet beans and corn silage when fed to fattening steers and also to compare the relative feeding value and economy of whole velvet beans in the pod and velvet beans crushed with the pods. The experiments are being continued, and while no detailed results have as yet been published, the following table gives a summary of the data obtained:

TABLE 5.—*Velvet beans in pod compared with velvet beans and pods crushed.*

[Cattle-feeding experiment at Collins, Miss., Jan. 1 to Apr. 5, 1918—94 days.]

Item.	Lot 1. Beans in pod and corn silage.	Lot 2, Beans and pods crushed and corn silage.
Number steers in lot	11	11
Average daily ration per head (full feed):		
Velvet beans in pod ... pounds	10.9	....
Velvet beans, crushed ... do	....	10.9
Corn silage ... do	22.0	22.0
Average initial weight per head ... do	660	660
Average final weight per head ... do	793	790
Average total gain per head ... do	133	130
Average daily gain per head ... do	1.41	1.38
Silage consumed per hundredweight gain ... do	1,710	1,717
Velvet beans consumed per hundredweight gain ... do	621	621
Feed cost per 100 pounds gain	$11.72	$13.29
Average shrinkage in transit to market ... pounds	79	79
Average dressing, market weights ... per cent	56.1	55.22
Initial cost per 100 pounds	$7.50	$7.50
Selling price per 100 pounds	$12.00	$12.00
Average profit per head	$13.70	$11.61

Twenty-two head of native Mississippi steers from 3 to 5 years old, showing no evidence of improved beef blood and averaging 660 pounds, were used in this test. Preliminary to being placed in the feed lots the steers were pastured on cornstalk and velvet-bean pasture for 28 days. The corn had been snapped and the unpicked beans left in the field were estimated to average 500 pounds an acre. The steers made an average daily gain of 1 pound a head on pasture.

When taken off pasture the steers were divided into two lots and fed 94 days. Lot 1 was fed whole velvet beans in the pod and corn silage. Lot 2 was fed velvet beans and pods crushed and corn silage. No other roughage or concentrate was fed. Both lots were fed in a similar manner, the only difference being in the preparation of the beans for Lot 2. The average daily ration per head on full feed was 10.9 pounds of velvet beans and 22 pounds of corn silage. Corn silage was valued at $5 a ton and whole velvet beans at $25 a ton. The charge for crushing the beans was $4 a ton, making them cost $29.

The steers of Lot 1, getting whole beans, relished their ration, while the steers of Lot 2, getting crushed beans, would not clean up their feed as fast nor consume as much as Lot 1 had the latter been allowed to eat as much as they wished.

The average daily gains, 1.41 pounds and 1.38 pounds for Lots 1 and 2, respectively, were practically the same and were satisfactory for the class of steers and the rations fed.

The amount of feed consumed per 100 pounds gain was almost identical in both lots. The quantity of silage consumed per 100 pounds gain was very low, owing to the large quantity of roughage in the bean hulls.

The feed cost per 100 pounds gain was $11.72 and $13.29 for Lots 1 and 2, respectively. Since the pounds of feed consumed per 100 pounds gain was almost identical in both lots, the extra cost of $1.57 per 100 pounds gain in Lot 2 was due to the charge for crushing the beans. It is interesting to note that Lot 1 made gains for less cost per 100 pounds than the selling price, which was $12 for both lots.

The steers were 96 hours in transit to market, with a resulting heavy shrinkage. Lot 1 dressed by market weights 56.1 per cent, and Lot 2, 55.22 per cent.

The plan of the experiment was to carry the steers for a longer feeding period, but the silos at the station were destroyed by fire, making it necessary to ship at once. In general, however, the steers were fairly well finished for steers of their quality, as is shown by the dressing percentages.

Hogs following the steers without other feed did not make satisfactory gains. The hogs following the steers that got crushed beans lost weight at the time the steers were on full feed.

The results of this experiment indicate that velvet beans and corn silage make a satisfactory ration for fattening steers and produce economical gains. The steers in the lot receiving whole beans in the pod consumed their feed more readily than the lot getting ground beans. They also made larger daily gains, cheaper gains, and dressed a higher percentage by market weights. The added cost of preparing the beans for Lot 2 reduced the profit $2.09 a head. These steers sold for $12 per 100 pounds, which was the highest price ever paid at the St. Louis market for native Piney Woods steers up to that time. However, fat grade steers showing crosses of pure-bred beef blood, and averaging 1,247 pounds each, sold the same day for $15.25 per 100 pounds.

At the station during the winter of 1917, 18 head of grade breeding cows, 7 of which had calves at foot, were fed a maintenance ration of corn silage and velvet beans in a dry lot. The cows maintained their weight for 46 days on a ration of 20 pounds of silage and 4 pounds of velvet beans in the pod. The cost of this ration per head was 10 cents a day when silage was charged at $5 a ton and velvet beans at $25 a ton.

Twenty head of pure-bred breeding cows, 4 of which had calves at foot, were fed 70 days on a ration of velvet beans crushed in the pod, and corn silage. These cows gained 15 pounds a head for the period on an average daily ration of 7.9 pounds beans and 26.5 pounds of silage. The cost of the ration was 18 cents a day when silage was charged at $5 a ton and ground beans at $29 a ton.

Although the high value of velvet beans as a soil-improving crop and a cheap home-grown feed are now generally recognized, as is evidenced by the enormous increase in the acreage grown in the last few years, the possibilities of this feed have been barely touched even in the region which is its natural home. To northern and western feeders who annually buy large quantities of protein feeds the velvet bean is still a curiosity. A few years ago the Piney Woods were looked upon as a future field for the production of large numbers of feeder cattle, to be shipped to other sections for finishing, because no crop had been found which would produce large quantities of feed for fattening cattle. Already that region has become a heavy buyer of western cattle to consume its velvet-bean crop, for which there was no other market except through cattle.

Corn is fed to cattle in that region in very limited quantities. The total production of corn is not great and some is shipped in each year to be utilized as feed for work stock and for fattening hogs.

Cottonseed meal, until the advent of velvet beans, was the concentrate most generally used for feeding cattle, but in recent years its use has diminished rapidly to give place to velvet beans, which could not be marketed so readily as a commercial feed. The demand for cottonseed meal for shipment is such that velvet beans are usually a more economical feed for cattle. The value of cottonseed meal as a cattle feed is so well known generally that it needs no discussion here.

Peanut meal, a by-product of the manufacture of peanut oil, is now produced in some sections of the Piney Woods in considerable quantities and is rapidly gaining favor as a feed for cattle. According to analysis, "peanut-oil cake" and "peanut-oil meal," made from shelled nuts, are practically equal to cottonseed meal, but their comparative value for feeding cattle has not been determined. Peanut meal is extensively used and is valued highly as a cattle feed in Europe.

Peanut hulls are high in fiber and have no higher feeding value than grain straw. Peanut meal from unshelled nuts contains about one-half as much crude protein as the meal made from shelled nuts. The hulls are often ground and added to the meal as an adulterant to give bulk to the feed.

The American feed-control officials classify "peanut-oil cake" and "peanut-oil meal" as products made from shelled nuts. When unhulled nuts are pressed the product should be labeled "unhulled peanut-oil feed" and the ingredients given as peanut meal and hulls.

Some of the most valuable protein concentrates, both commercial and farm grown, are now produced in the Piney Woods region in sufficient quantities to fatten a much larger number of cattle than are now produced. When it is considered that less than 10 per cent of the land is in cultivation the possibilities for feed production become apparent.

SILAGE CROPS.

Corn is the most generally used and most reliable crop for silage in that region and is considered superior to any other silage. From 5 to 6 tons of silage is a fair average yield. On the richer lands and on lands well fertilized the yields run as high as 10 to 12 tons an acre. The long growing season permits corn planted the first of July to mature for silage and a crop of corn for silage commonly follows oats.

Sorghum ranks next to corn as a silage crop and exceeds corn in the tonnage per acre. Sorghum silage is practically equal to corn silage in feeding value, although the latter is usually preferred. Sorghum in that section is a very reliable crop and is much more easily saved as silage than as hay.

Corn-and-velvet-bean silage has been used in a very limited way because of the difficulty of cutting the crop and removing it from the fields, but where the crop has been utilized in this manner it has met with instant favor. The silage is dark in color but of excellent quality and is eaten greedily by cattle. Since the beans are later in maturing than the corn, the corn is left until well matured. The dry fodder improves the keeping quality of the beans so that the silage does not become rank and black as does silage made from a legume alone. The velvet bean increases the protein content of the silage to a marked degree and the analysis would indicate a higher feeding value than corn or sorghum alone. Early varieties of beans are sown when the crop is to be harvested as silage, as they are more nearly mature at the time the corn is ready to cut and the vine growth does not interfere so seriously in removing the crop from the field.

Table 6 gives the analysis of a single sample of corn-and-velvet-bean silage as compared with analyses of corn silage and sorghum silage.

TABLE 6.—*Analyses of corn-and-velvet-bean silage as compared with silage made from corn and from sorghum.*

Kind of silage.	Number of analyses.	Constituents.					
		Water.	Ash.	Crude protein.	Carbohydrates.		Fat.
					Crude fiber.	Nitrogen free extract.	
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Corn and velvet beans [1]	1	73.7	1.0	3.5	5.5	15.6	0.7
Corn [2] (well matured)	121	73.7	1.7	2.1	6.3	15.4	.8
Sorghum [2]	30	77.2	1.6	1.5	6.9	11.9	.9

[1] Analyzed by the Bureau of Chemistry, U. S. Department of Agriculture.
[2] Analyses from Henry and Morrison.

Table 6 shows the analysis of corn-and-velvet-bean silage to be very similar to corn silage and sorghum silage except that there is a very marked difference in the quantity of crude protein. The crude-protein content is more than double that of sorghum silage and nearly double that of corn silage. The crude-fiber content is also very low and is less than that of either sorghum or corn silage. The analysis would indicate a higher feeding value for corn-and-velvet-bean silage than corn or sorghum silage alone.

Japanese cane has been used to some extent as a silage crop because of its heavy yields, but it has not been generally satisfactory. This crop bears no grain and the silage is low in crude-protein content and somewhat high in fiber content. The silage is usually of poor quality and not equal to corn or sorghum silage in feeding value.

RECOMMENDATIONS FOR WINTER FEEDING.

Roughages should be used to the fullest extent as winter feed. Provision must be made for feeding at least 3 months and the use of large quantities of roughage is the most economical method of wintering cattle. Every effort should be made to increase the production of forage crops, especially the legume hays and silage crops. To save roughages properly in that region, where summer rains are frequent and the moist atmosphere favors rapid spoiling in the field, more attention must be given to storing under cover. Sufficient mow space should be provided in barns to store all hays.

Silage may be made largely regardless of any weather conditions. Practically the entire feeding value of a plant is utilized when stored in the silo; this is a particular advantage with corn, which is the most reliable silage crop grown in the Piney Woods.

Corn is cut for silage at a time when the plant has the highest feeding value. In the case of the rank-growing southern varieties of corn about half of the feeding value of the plant is left after the ear is removed. When fed as silage the entire plant is consumed without waste, but if the ear is snapped and the stalks left in the field the sustenance leaches away rapidly, much of the feed is trampled down, and only a small percentage of the feeding value is utilized. Cutting the corn and curing into stover give uncertain results unless it is protected from the weather.

Corn and velvet beans make the greatest tonnage per acre of all silage crops grown in the Piney Woods and the silage has a very high feeding value due to the high protein content. The difficulty of harvesting the crop because of the heavy vine growth is the only obstacle to the general use of velvet beans as silage.

Where lumber is so plentiful a silo should be on every farm where cattle are raised, but on inquiry of all owners of pure-bred bulls, so far as lists are available, it was found that less than 1 per cent were using silos. The silo is a most valuable piece of equipment for the cattle farm and should be constructed even before cattle are purchased.

Velvet beans, in view of their adaptation to the region and the enormous quantity produced, should be the chief concentrated feed used. The value of this feed is not fully appreciated and a large proportion of the total acreage is now being used as pasture in a wasteful manner. Inquiry in every county of the Piney Woods brought out the fact that it is almost a universal practice to pasture all beans used as feed on the farm where grown. Most farmers provide no other feed for wintering cattle and many men use velvet-bean pasture in preference to silos.

Velvet beans in the pod are equal in feeding value to wheat bran and have about half the value of high-grade cottonseed meal. Certainly no farmer would allow his breeding cattle to run to the bin and eat their fill of bran or cottonseed meal. Turning stock cattle on bean fields means practically the same thing as giving them a fattening ration of a protein feed instead of a maintenance ration.

It must also be borne in mind that the grazing is the best when the cattle are first turned on the pasture and gradually dwindles to nothing. This condition is always true in grazing velvet beans and is the opposite of what it should be for fattening cattle. For maintaining cattle the ration should be constant, with a limited quantity of concentrate and all the roughage they will eat.

In an experiment at Collins, Miss., which has been previously mentioned, 78 head of mature cattle exhausted a 40-acre field of velvet beans in 28 days. It is evident that no measure of the yield of beans could be taken, but the estimated average of 500 pounds per acre was below the estimate of farmers accustomed to having beans picked from the field by the hundredweight. With an average of 500 pounds to the acre this field contained 20,000 pounds of beans, and if the beans were all consumed without waste the average daily ration of beans was 9.1 pounds a head. This ration was about right for fattening cattle but was excessive for breeding cows, and the cows made an average daily gain of 1.25 pounds a head. From this experiment conclusions were drawn as follows:

> In view of the scarcity of labor and the high cost of picking beans the pasture furnished economical feed for fattening cattle. However, it would not appear profitable to turn stock cattle on velvet-bean fields yielding more than 500 pounds an acre unless they could be allowed to run on the field a short period each day, as the beans would be less efficiently used than if picked and hand fed.

Where beans make a heavy yield, stock cattle should be turned on the field only 1 or 2 hours each day, depending on the ease with which the cattle can get a fill of beans. Late in winter and in spring the bean leaves and stalks do not supply roughage enough and some other roughage, such as the grass remaining on the range, should be fed as a filler. A reserve supply of beans should be picked to feed when the bean pastures fail, which usually happens when the cows are heavy with calf and need feed the most.

Velvet-bean pasture may be used economically for fattening cattle, but steers should be removed when the pastures begin to fail, and should be kept on heavy feed until finished for market, leaving the remaining beans in the field to be cleaned up by stock cattle.

The only method of completely utilizing the velvet-bean crop for winter feed is to ensile it. This clears the field in time to plant a cover crop of rye for winter and spring grazing; the carrying capacity of a given acreage in feed crops may be doubled or trebled in this manner. By planting the early maturing varieties of beans which do not make a heavy vine growth the crop may be handled for silage without excessive labor.

The velvet bean is so valuable as a feed that it should be utilized to the fullest extent. Production of the bean crop at a very low cost does not affect its value as a feed after it is produced and is not a logical reason for using it in a wasteful manner.

Cottonseed meal should not be used as fertilizer until it has been fed to cattle. Enormous quantities of cottonseed meal are used in the Piney Woods as a direct fertilizer when it could be fed to cattle and fully 75 per cent of the fertilizing value recovered and applied to the land in the form of manure.

BUILDINGS AND SHELTER.

Because of the short, mild winters cattle need little shelter and no expensive buildings are necessary. Cattle seek protection only

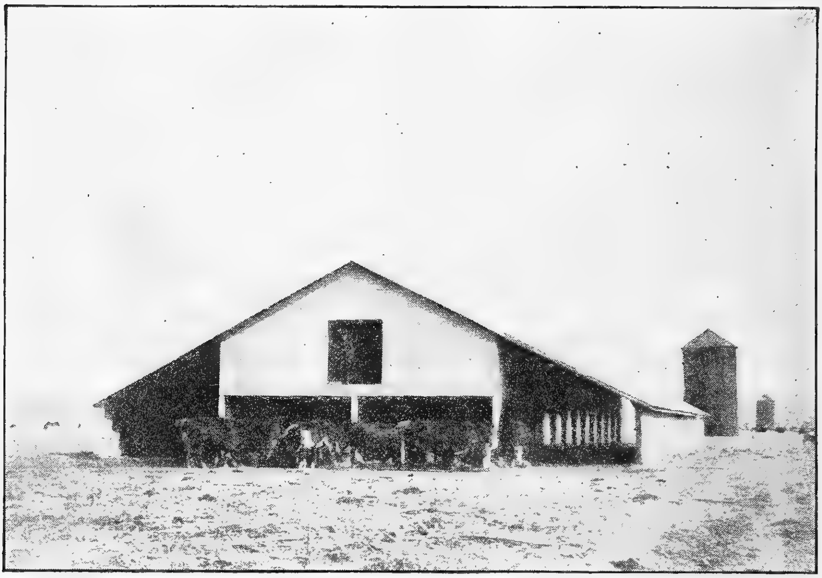

FIG. 11.—An open shed for cattle on a Louisiana ranch.

from the cold winter rains of December, January, and February and a dry place to lie down is all that is needed. Mature cattle should not be closely housed and cattle space under barns should be boarded up only on the side of the prevailing winds.

Where the land is not heavy enough to be injured by trampling, cattle will do better if allowed to run in the open with available shelter when needed. Where velvet beans are pastured during winter, shelter should be provided, as exposure to cold rains causes the rapid loss of expensive gains.

Figure 11 shows an inexpensive type of open shed used on a Louisiana cattle ranch. Such a shed provides all the shelter necessary.

In the Piney Woods region, where rains make the curing of hay difficult, barns should have ample storage space to take care of roughage for winter feed. Although lumber is plentiful, barns commonly follow the sawmill or cotton-gin style of construction and provide little mow space except for baled hay. Figure 12 shows a barn of the hip-roof or truss-frame method of construction on a cattle ranch in Mississippi. This is an inexpensive type of cattle barn which has a large storage space for loose hay. Working plans for constructing the barn may be obtained on application.

DISEASES AND PESTS.

The cattle tick (*Margaropus annulatus*), which is the carrier of the disease known as Texas or splenetic fever, is the only pest that has been a real detriment to the development of the cattle industry

FIG. 12.—Modern cattle barn on the experiment farm at Collins, Miss. With the exception of the roof this barn was constructed of used lumber from abandoned "dummy-line" trestles and mill timbers. Note the storage room above and the daylight underneath.

of the Piney Woods region. The native cattle become immune from the disease through contracting it in a mild form as calves, but mature animals brought in from Northern States or tick-free territory are very susceptible. The disease appears in from 13 to 90 days after exposure and is fatal in 90 per cent of the cases in mature susceptible cattle. The damage done consists of the loss of animals from the fever, the extra feed needed to support the blood-sucking parasites, the penalty placed on quarantined cattle at the markets, and the prevention of the bringing in of pure-bred animals for improvement of the herd. The total damage has been beyond reasonable estimate. In 1906 the Federal Government and State and local authorities began the systematic eradication of the tick and great progress has been made in recent years. The entire States of Mississippi and South Carolina are now released from quarantine and the States of Louisiana, Alabama, Georgia, Arkansas, and Texas have compulsory State-wide dipping laws in effect. It is expected that the Texas-fever tick will be entirely banished from this region by 1923. Cattlemen contemplating the purchase or lease of lands should be familiar with prevailing conditions. Many local areas and counties are being released from quarantine from time to time and anyone contemplating the movement of cattle into the Piney Woods region should write to the Chief of the Bureau of Animal Industry, Department of Agriculture, Washington, D. C., for the latest regulations defining the territory.

Mosquitoes and flies, which are often given as a serious objection to cattle raising, are not of any considerable economic importance in the Piney Woods region.

Screw worms are prevalent in the western portion of the region, but the damage is avoided by dehorning and castrating animals in cool weather, when the flies are not active.

Anthrax or charbon is not prevalent, although it is known to occur. Regions which are low and swampy are much more subject to this disease than the dry, sandy pine lands. The disease may be prevented by vaccination.

Blackleg occurs, but is no more prevalent than in other sections of the country. As a precaution young cattle should be vaccinated each year.

Tuberculosis is a disease practically unknown among the native cattle. This is no doubt due to the hardiness of the animals and the lack of close housing. With the eradication of the cattle tick there is no disease or pest that can be termed an economic barrier to beef-cattle production. Although the common diseases to which cattle are subject are present they are no more prevalent than in other regions, and the native cattle are subject to tuberculosis in a markedly less degree than northern cattle.

In purchasing northern cattle for breeding purposes extreme care should be taken not to introduce tuberculosis into the herd. Regulations require the testing of cattle for interstate shipment, and cattle should be purchased subject to retest.

WATER SUPPLY.

Next to abundant pasture an abundant supply of water is an indispensable feature of desirable cattle range. Water must be had at any cost, and where the supply is not dependable from year to year the cost of deep wells is well-nigh prohibitive for the man with a small number of cattle.

The natural water supply of the Piney Woods region is very abundant. The heavy rainfall supplies many springs, which furnish a constant supply of running water in practically all pastures. Where the surface supply of water is not constant, an ample supply of water may be obtained from wells at a depth of from 30 to 50 feet. In many places flowing artesian wells may be obtained, but at a greater cost than wells which strike the water table only.

Although most of the Piney Woods region is well watered, many pastures are supplied by water holes only at the time when the pasture is at its worst. These water holes usually have a heavy clay bottom and should be enlarged into ponds deep enough to prevent the cattle from fouling them by standing in the water, and large enough to hold water for any emergency.

In the flatwoods and sandy sections wells and storage tanks should be provided to prevent cattle from going long distances to water.

MARKETS.

The cut-over pine lands of the South naturally do not have great cattle markets such as have been built up in cattle-producing sections. As one lumberman expressed it: "We would not build our sawmills and wait for the timber to grow and we can not expect to have big packing plants until we raise the cattle." Many small plants are operating, however, and the large packing-house companies are enlarging their establishments at the southern markets in anticipation of the eradication of the cattle tick.

Some cattle are shipped from South Carolina and Georgia to Richmond and Baltimore, but most of the cattle from Florida and southern Georgia go to the Jacksonville market. Some Florida cattle are still exported to Cuba from Tampa. Most fat cattle from Alabama, Mississippi, and Louisiana go to the St. Louis, New Orleans, and Fort Worth markets. Packing plants at Jacksonville and Chipley, Fla.; Moultrie and Macon, Ga.; Andalusia, Mobile, and Birmingham, Ala.; Natchez and Vicksburg, Miss.; and New Orleans and Baton Rouge, La., are having a stimulating effect on the cattle industry of the region.

The Piney Woods region is well supplied with means of transportation. Lumber operations on a large scale necessitated the building of many railroad lines which interlace the whole territory, and it is not necessary to make long drives to a shipping point in any section. Moreover, bad wagon roads make it a distinct advantage to market home-grown feeds through cattle.

Figure 13 shows the distance to the principal markets from a central point in the cut-over region and the location of packing plants under Federal inspection.

EXPERIMENTAL WORK OF IMMEDIATE IMPORTANCE.

The changes and developments in the beef-cattle industry of the Piney Woods are so recent and unexpected that very few improved methods of management have been applied even in a particular locality. Practically no cattle farms or ranches have been established long enough to be pointed out as practical demonstrations. The question, "How long have you used a pure-bred bull?" was

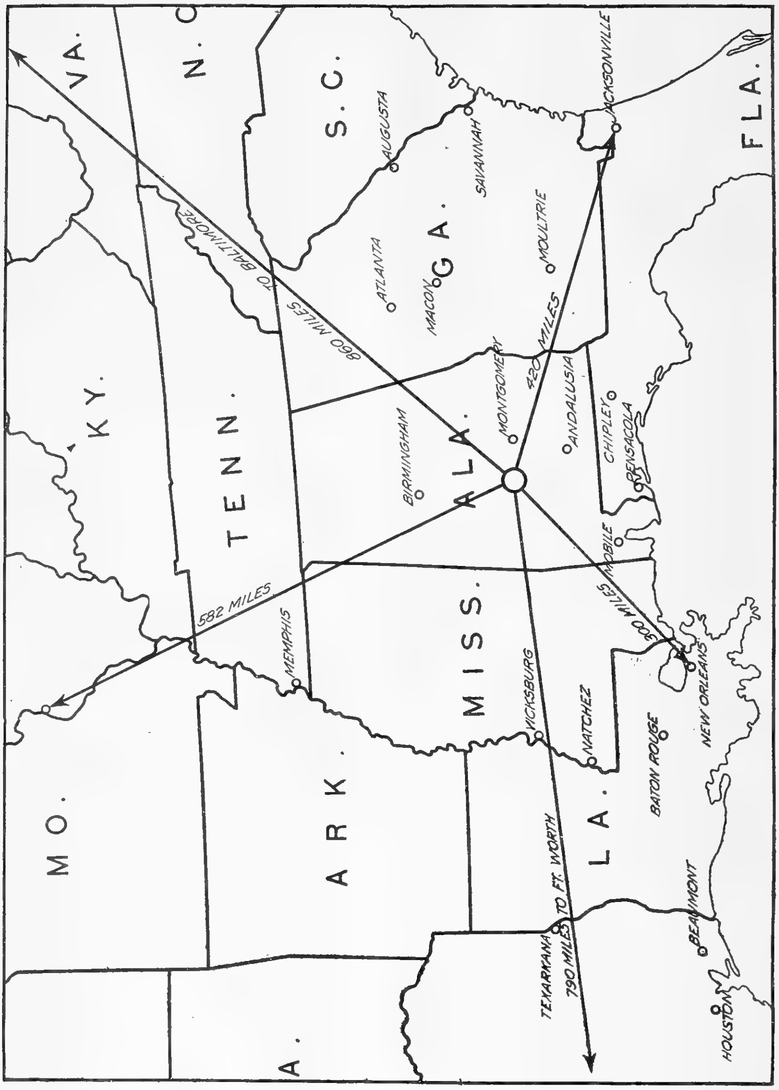

FIG. 13.—Location of principal southeastern markets and packing plants.

asked of every owner of a pure-bred bull in the Piney Woods, so far as lists were obtainable, and the average length of time given in the answers was less than 4 years. Four years is hardly time enough to put a cattle farm on a paying basis.

The crop rotations are not limited to corn, oats, wheat, and clover, or similar rotations, as is common in most cattle-producing sections, where certain general practices become well established. So great a variety of feed and forage crops is grown that men on adjoining farms may follow different methods in the management of their cattle, each advocating his method as the best. Therefore the demand for definite information concerning the region is insistent.

In answer to questionnaires 51 per cent of the lumbermen who did not already own cattle stated they were interested in the purchase of cattle to put on their lands. In entering the cattle business in this region, however, each man has to do his own experimental work according to his individual needs, because of the lack of any other source of information. Such information as the private owner may obtain, even though it is accurately recorded, is not available to the public and its value is lost. Many problems must be worked out locally by the individual, but such problems as the improvement of the pastures and the utilization of velvet beans are of such general importance that immediate experimental work is imperative. Other problems necessarily are connected and should be worked out at the same time.

Pasture problems involve the practical application of the present agronomic knowledge of the pasture plants adapted to the Piney Woods. Accurate data are needed concerning the relative merits of these plants as determined by methods of establishment, cost of establishment, ease of maintenance, and productive value when grown on a scale sufficient for the commercial production of cattle. Methods must be worked out to protect the desirable pasture plants now found on the range, and to facilitate their reseeding and natural spread so that wire grass and broom sedge may be replaced.

Feeding problems involve the use of home-grown feeds for wintering cattle and fattening for market. The economical use of velvet beans, silage, and legume hays is of particular importance.

The problems of herd management under Piney Woods conditions involve systems of breeding, handling the herd, methods of summering and wintering, prevention of disease, and marketing, on all of which accurate data must be obtained before the business in that section can be conducted on a safe basis.

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No. 375.

LINNEAN SOCIETY OF LONDON.

GENERAL MEETING.

6th May, 1920.

Dr. A. Smith Woodward, F.R.S., President,
in the Chair.

The Minutes of the General Meeting of the 15th April, 1920, were read and confirmed.

The report of the Donations received since the last Meeting was laid before the Fellows, and the thanks of the Society to the several Donors were ordered.

Mr. Arthur Lionel Goodday was admitted a Fellow.

Mr. William Henry Kitching, Mr. Chintaman Mahader Tembe, Mr. Rowland Maurice Richards, The Vicomte de Sibour, F.Z.S., Mr. Rustom Hornnasji Dastur, B.Sc. (Bombay), and Mr. John William Bodger, were proposed as Fellows.

Certificates in favour of the following were read for the second time:—Mr. Edmund Gustavus Bloomfield Meade-Waldo, Mr. Pyari Mohan Debbarman, B.Sc., Prof. Otto Vernon Darbishire, B.A., Ph.D., Mr. William Rickatson Dykes, M.A.(Oxon.), L. ès L. (Paris), Prof. Shankar Purushottam Agharkar, M.A., Ph.D., Dr. John Wishart, Capt. Eric Fitch Daglish, Ph.D., Mr. Bertram Henry Buxton, and Prof. Otto Rosenheim, Ph.D., F.C.S.

The following were balloted for and elected:—

Fellows: Mr. Sydney Percy-Lancaster, F.R.H.S., Mr. Herbert William Pugsley, B.A.(Lond.), Mr. Joseph Omer-Cooper, Miss Lucy Ellen Cox, B.Sc.(Lond.), Dr. George Kenneth Sutherland, M.A., Mr. Harry Bertram Harding, F.R.M.S., and Mrs. Elinore Egerton Harde.

Foreign Members: Prof. GASTON BONNIER, Prof. VICTOR FERDINAND BROTHERUS, Prof. GIOVANNI BATTISTA DE TONI, Prof. LOUIS DOLLO, Prof. PAUL MARCHAL, and Prof. ROLAND THAXTER, Ph.D.

The President remarked upon the recent issue of two new volumes of the Ray Society, which were shown on the table, namely, 'British Orthoptera,' by Mr. Lucas, and the first volume of the 'British Charophyta,' by Mr. Groves and Canon Bullock-Webster.

The following auditors were proposed, and elected by show of hands:—

For the Council: Mr. E. T. BROWNE,
Mr. STANLEY EDWARDS.
For the Fellows: Mr. T. A. DYMES,
Mr. R. PAULSON.

Dr. G. P. BIDDER, F.L.S., read three communications on Sponges, of which the following abstract was supplied by the author:—

(1) "The Fragrance of Calcinean Sponges."—Clathrinidæ have a noticeable aromatic scent. probably due to the excretory granules which give their bright colours. These granules especially surround the pores. May this be to attract the spermatozoa? I have not seen the fine-lashed spermatozoa of Poléjaeff, but in *Sycon* have observed a stiff-tailed organism—possibly the result of curious gregarine-like objects produced in cells resembling gonocytes. The algæ, which I described as the food of collar-cells, Dendy calls sperm-morulæ and the cell-fæces spermatozoa—interpretations which seem improbable. The "sperm-balls" of *Clathrina* may be the same alga. In *Guancha coriacea* I observed the "minute wandering cells" escaping as a cloud; probably these are spermatozoa.

(2) "*Syncrypta spongiarum*" (wrongly assigned to *Pandorina* in my MS.) I give as a name to the "alga" above-mentioned. I suggest that it is a dangerous parasite, against which *Grantia compressa* has a successful phagocytosis, but that certain other sponges are hosts for its *Palmella* stage.

(3) "Notes on the Physiology of Sponges."—(A) Cercids, proposed as a name for the "minute wandering cells." (B) Cessation of the current in sponges. (C) Differences between Calcinea and Calcaronea in their porocytal granules and odour. (D) The excreta of

collar-cells are gelatinous globules containing dark particles. Probably Dendy is right in comparing these to the "spermatozoon-heads" of Poléjaeff, which may be the ultimate residue of victorious phagocytosis. (E) Origin of sponges. Archæocytes may have been differentiated into external excretory cells and internal reproductive cells; the former engulfed cercids, but only to pass them on to the latter. By abbreviation of this process the excretory cells may have become self-perforating porocytes, which were then adapted to supply water to flagellate cells in the centre of a *Protospongia*-like colony, thus converting it into an elementary *Olynthus*.

The discussion which followed was maintained by Prof. Dendy, Mr. Harold Russell, and Mr. J. B. Gatenby (visitor), the author replying.

Mr. Edward J. Bedford showed a series of thirty exquisite water-colour drawings from British Marsh Orchids, with their numerous varieties and hybrids, further illustrated by 70 lantern-slides from his photographs of the growing plants *in situ*, and enlarged views of the lip, front and side view.

Mr. H. W. Pugsley and Mr. T. A. Dymes contributed further remarks; the latter exhibited a series of fruit capsules, and remarked on the characters afforded by these variable plants, in their fruits and seeds; Mr. Bedford briefly replying.

The next Meeting will be the Anniversary, to be held on Thursday, 27th May, 1920, as previously announced on the Card of Meetings. See Special Notice enclosed.

The General Meeting following the Anniversary will be held on Thursday, the 3rd June, at 5.0 p.m.

COMMUNICATIONS.

1. Mr. R. Swainson-Hall, F.L.S.—Exhibition of 50 drawings of the Oil-palm, *Elæis guineensis*.
2. Mr. A. Whitehead, B.Sc.—Objects observed in the neighbourhood of Basra, during the war, with lantern-slides. (Communicated by Mr. H. Findon, F.L.S.)

3. Prof. W. J. Dakin, F.L.S.– Whaling in the Southern Ocean—lantern-slides.

The General Meeting to be held on the 17th June will be devoted to a celebration of the Centenary of Sir Joseph Banks, Bt. (1743–1820), with essays on various aspects of his life-work, and an exhibition, followed by a dinner.

IMPORTANT NOTICES.

The Council are compelled to call attention to the great increase in the cost of paper and printing, consequently it is urgently requisite that all papers should be condensed, and limited so far as possible, to the description of new results.

All parcels must now be PREPAID. Fellows are therefore requested, when writing to borrow volumes from the Society's Library, to remit the cost of carriage or to open a small Postal Deposit Account with the Treasurer.

Authors may have printed abstracts of their papers in slip form, by handing in their manuscript not less than fifteen days previous to the date of the Meeting at which they are appointed to be read; these abstracts should not exceed 200 words in length.

E. S. GOODRICH, }
A. B. RENDLE, } *Secretaries.*
B. DAYDON JACKSON, *General Secretary.*

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 828

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

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BACTERIAL WILT OF CUCURBITS.

By FREDERICK V. RAND, *Assistant Pathologist*, and ELLA M. A. ENLOWS, formerly *Assistant Pathologist, Laboratory of Plant Pathology.*

CONTENTS.

FOREWORD.

The studies of the writers on bacterial wilt of cucurbits (caused by *Bacillus tracheiphilus* Erwin F. Smith), published in 1915 and in the spring of 1916, have been continued during the past three seasons. The previously published work[1] demonstrated that the striped cucumber beetle (*Diabrotica vittata* Fab.) and also the 12-spotted cucumber beetle (*D. duodecimpunctata* Oliv.) are the most active and probably the only summer carriers of this bacterial wilt in the localities investigated. Some evidence was given that the striped cucumber beetle may be also a winter carrier.[2] It was shown that the soil had no relation to the disease either as a source of early spring or of summer infection. Seed from wilted plants in all cases failed to transmit the disease, and all attempts at infection through the stomata gave negative results. A fair degree of control was obtained by early treatments with Bordeaux mixture and lead arsenate combined, and it was shown that this control was related not only to the repellent and insecticidal qualities of the mixture, but also to a direct bactericidal action upon the wilt organism.

The present paper deals with further studies of the relation of soil and insects to the distribution and control of the disease, and includes also a portion of our work with the causal organism itself.

[1] Rand, F. V. Dissemination of bacterial wilt of cucurbits. (Preliminary note.) *In* Jour. Agr. Research, v. 5, no. 6, p. 257-260, pl. 24. 1915.

Rand, F. V., and Enlows, Ella M. A. Transmission and control of bacterial wilt of cucurbits. *In* Jour. Agr. Research, v. 6, no. 11, pp. 417-434, 3 figs., pl. 53-54. 1916.

[2] Other species of Diabrotica have not been tested.

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SUMMER TRANSMISSION OF WILT.

DIRECT INSECT TRANSMISSION EXPERIMENTS.

The earlier experiments on insect transfer of the wilt disease have been repeated many times during the past three years (1916–1918) with results similar to those already published. As an example of the method used the following details may be given:

September 17, 1916. Twelve squash bugs (*Anasa tristis* De G.) were fed four days upon cucumber plants wilted from pure culture inoculation. Two bugs were then caged (Pl. I) with each of six healthy cucumber plants for two days, during which time they were all observed to have fed. The plants at this time had become slightly flabby as a direct result of the insect feeding. However, this condition practically always results from squash-bug injury to young cucumber plants and is in no way connected with bacterial wilt. Cultures and microscopical examination in such cases fail to show bacteria present; the flabbiness often begins to appear within a few hours after the bugs start feeding, while wilt at the very earliest does not appear sooner than three to five days after inoculation; this flabbiness at once affects the plant as a whole, while in the bacterial disease the wilting is progressive from the point of inoculation; and finally, unless too far gone, plants always recover their turgor after the squash bugs are removed, while vigorous young cucumber plants inoculated with virulent strains of bacterial wilt have never been known to recover. In this experiment the squash bugs were all removed after two days and the plants soon regained their turgor. Although under observation until October 13, no wilt developed. This experiment was repeated many times with like results.

The squash lady bird (*Epilachna borealis* Fab.) was tested in 10 or more further sets of experiments, but no wilt ever followed its injuries to healthy cucumber plants, and negative results were obtained by inoculation with intestines of wilt-fed individuals (see p. 24).

The cotton aphis (*Aphis gossypii* Glov.) and the potato flea-beetle (*Epitrix cucumeris* Harr.) were also retested by similar methods and the negative results confirmed by observations in the experimental fields. Furthermore, in the field cage experiments they have always had access through the wire netting to the cucurbit plants within, but have never carried the disease from the numerous wilt cases in the surrounding field. These observations corroborate the results of the direct experiments.

During August, 1917, honeybees (*Apis mellifera* L.) were collected at random from the experimental cucurbit field where wilt was prevalent, and many were taken directly from blossoms of wilting vines. One to several bees were placed in 15 large cages containing cucumber or cantaloupe vines (Pl. II, fig. 1). No wilt followed in any case. It might be noted in passing that the cucumber fruit set very much more freely in these cages than where bees were excluded.

These five different species have all given constantly negative results, while the striped and 12-spotted cucumber beetles tested in the same way have repeatedly given positive results. For example, using the striped beetle in 10 direct experiments (1916 and 1917) similar to the one detailed above for the squash bug, 7 out of the 10 tests gave positive results. In these cases the beetles were fed upon wilted leaves and then caged with cucumber plants for a sufficient length of time to determine the result. These experiments were entirely separate from the successive infection experiments detailed later (cf. p. 21, 22). The 12-spotted cucumber beetles have not been tested so fully, but sufficient work has been done to show that they are also capable of direct wilt transmission.

TRANSMISSION FROM RANDOM COLLECTIONS OF BEETLES.

Collections of striped cucumber beetles and 12-spotted cucumber beetles taken at random in the fields have given widely varying results as to wilt transmission according to time of year, prevalence of wilt, amount of territory devoted to cucurbits, and length of time the beetles had fed since attaining the adult stage. In eastern Long Island from the first collections of early spring only an occasional striped beetle has proved to be a wilt carrier. Later in the season some collections have shown a large percentage capable of spreading the disease. For example, on September 1, 1916, striped beetles were collected at random in a cucurbit field and several put into each of four beetle-proof cages containing healthy cucumber plants. Many of the vines in each of the cages contracted bacterial wilt, so that at least one of the beetles introduced into each cage must have been a wilt carrier. About two weeks previously six beetles collected in the same locality failed to give infection. In this locality late cucumbers constitute one of the main crops.

However, in the trucking sections around the District of Columbia late cucurbits are rather the exception, most of these crops being planted there in early spring. In that locality random collections from the field have given a much smaller percentage of infection. During the summer of 1917, at Tuxedo, Md., from five to seven large insect cages were kept constantly as storage cages for both species of cucumber beetles. Healthy plants grown in the cages and healthy potted cucumber plants brought frequently from the greenhouses at Washington, D. C., were kept in the cages as food for the beetles. Collections of beetles made at frequent intervals from fields where wilt was present were placed in these cages, but throughout the season only two cases of wilt occurred in these cages. In many instances the beetles were taken directly from wilting vines.

Twelve striped beetles, among the first of the season found, were collected May 20, 1918, in an early cymling field at Kenilworth, D. C. Careful search over the field failed to reveal any cases of wilt. These beetles were caged for four days with 10 cucumber seedlings, after which the plants were held for observation in a beetle-free cage. On June 4 two of the ten plants had wilted. Cultures were made and *Bacillus tracheiphilus* was isolated and tested by successful inoculations.

In a large collection of striped beetles made at Norfolk, Va., about October 1, 1916, wilt resulted in one out of several cages among which the beetles were distributed.

In most instances only a very small proportion of the cucumber beetles present in a field actually carry infection.

The truth of this statement is seen at once when one thinks of the large numbers of beetles often present in a field during their maximum prevalence. If any considerable proportion were carriers of wilt not a single plant could escape infection at some time during the season.

WILT CURVES VERSUS BEETLE CURVES.

In a preceding publication[1] by the writers a discussion was given of the records of striped-beetle prevalence versus wilt prevalence (1915) in three experimental fields at East Marion, Long Island (fig. 1, Fields I, II, and III). The graphs here reproduced (fig. 2) show that a definite relation existed between rise and fall in beetle and wilt curves under two sets of conditions in which the beetles, appearing at widely different dates, were the variable environmental factor. No

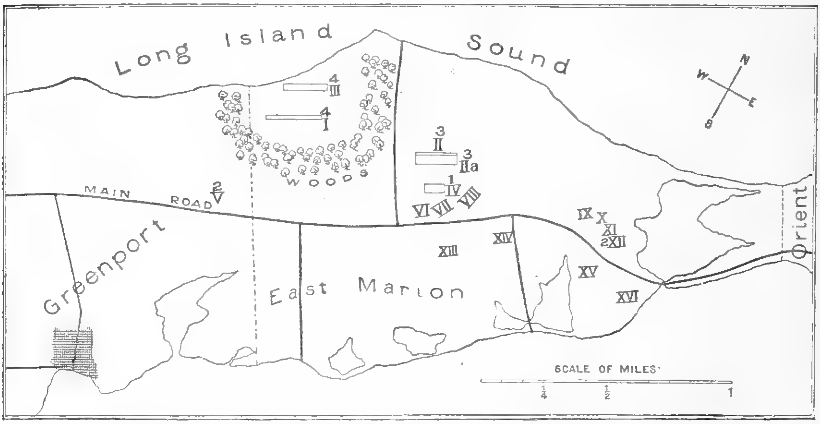

FIG. 1.—Map of northeastern Long Island, showing location of experimental fields I to IV and of wilt sequence records in fields I to XVI. The arabic numerals show the sequence of wilt appearance during the spring of 1916. (Map drawn by Wayland C. Brown, formerly of the Bureau of Plant Industry.)

direct relation to meteorological conditions could be found. In all three fields about one month intervened between the maximum prevalence of striped cucumber beetles and of bacterial wilt.

The wilt records of 1915 were made by counting at each date of observation all living cucumber plants infected with wilt and including not only all new cases but also any wilted plants that might have lived over from the time of the previous count. It was thought possible that by this method some cases might have been counted more than once, thus moving the maximum of the wilt curve forward too far. Therefore, during the following season (1916) in the same locality much more careful records were kept of both beetle and wilt prevalence in Fields II and IIa (figs. 1 and 3). At each date of beetle observation an area one-tenth the size of the whole field was measured off, and so far as possible all striped cucumber beetles in this area were

[1] Rand, F. V., and Enlows, Ella M. A., 1916. Op. cit., p. 420–423.

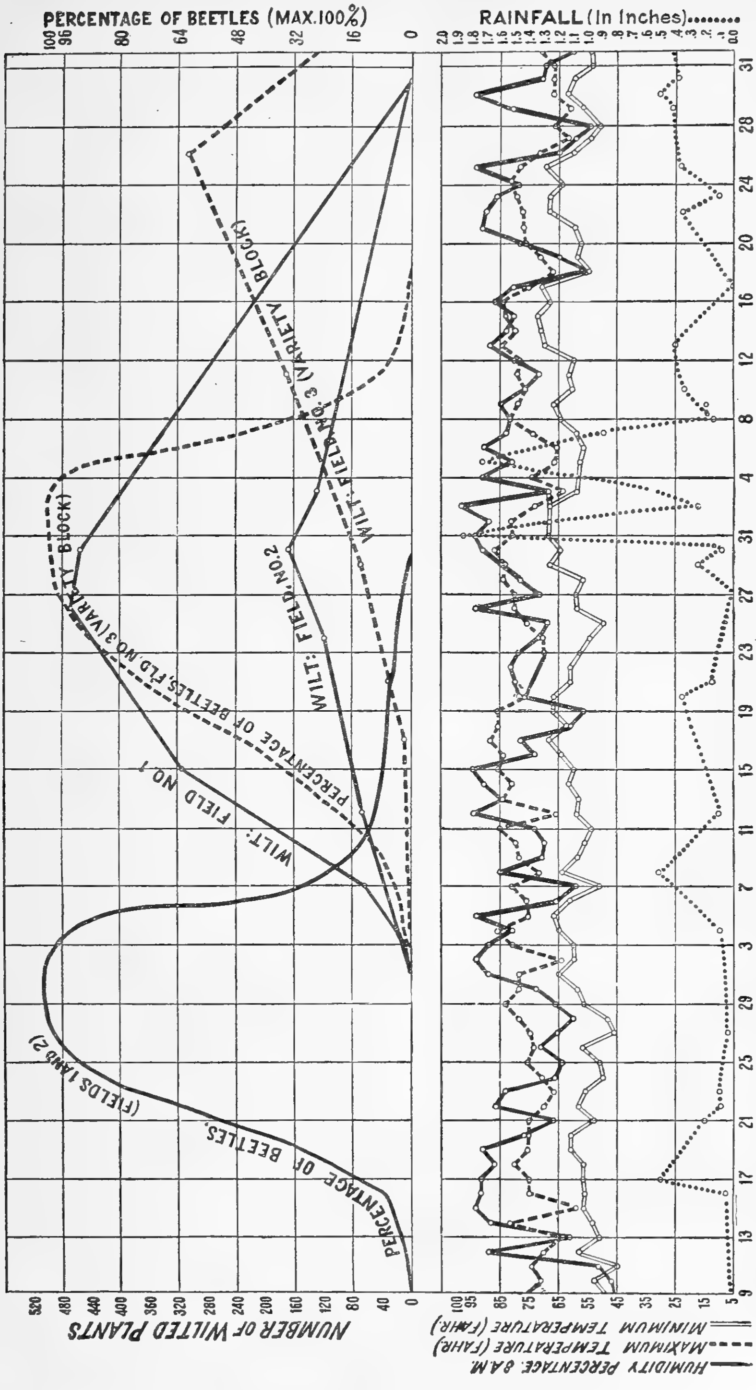

FIG. 2.—Comparison of the amount of wilt with the prevalence of the striped cucumber beetle and with meteorological phenomena in Fields I, II, and III, East Marion, Long Island, N. Y., season of 1915. (For the beetle curves, maximum prevalence is indicated at 100 per cent, regardless of the actual numbers present.)

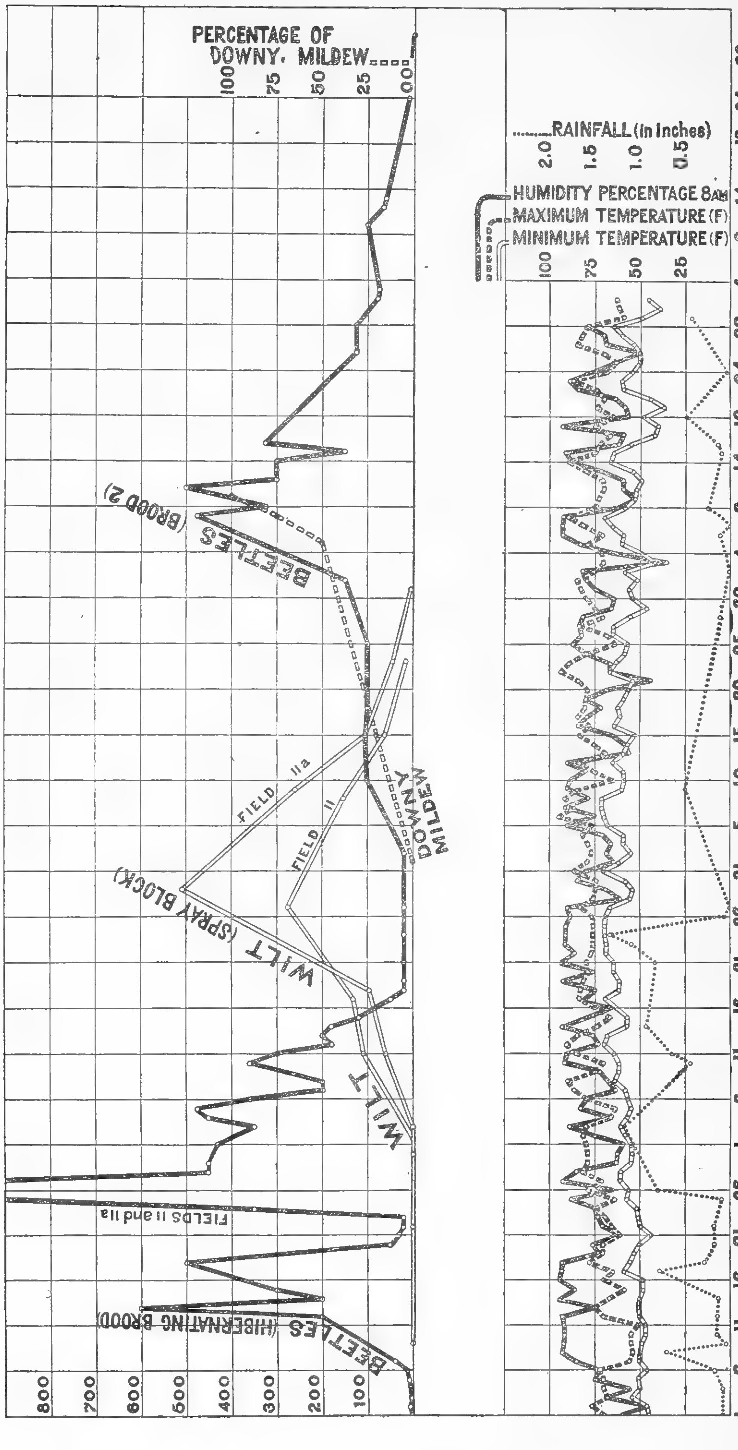

FIG. 3.—Comparison of the prevalence of wilt with that of striped cucumber beetles and with meteorological phenomena in Fields II and IIa, East Marion, Long Island, N. Y., season of 1916. (The downy-mildew curve is also shown. The beetle and wilt curves are based on actual numbers of beetles and cases of wilt present.)

counted. These figures were in each case multiplied by 10 to give the assumed actual number of beetles in the whole field at each date, and these totals were used in plotting the curves. Obviously it would be impossible to make these figures absolutely accurate, but the counts were carefully made, always by the same person, and were checked up by general observations over the field; and there is no doubt that the figures are comparable for purposes of plotting the curve.

In the case of the wilt records, each plant showing wilt was marked by a stake dated when the disease was first observed, and careful records were kept by row, hill, and plant, so that a wilted plant was counted once and only once. These records were as accurate as it was possible to make them.

During the summer of 1917, similar careful records were kept in the experimental field near Tuxedo, Md. The cucumber and cantaloupe spray blocks and the cucurbit variety block were all contained in one rectangular field of 1½ acres, and the beetle and wilt records cover this field as a whole. In the graphs (fig. 4) made from these figures the wilt is expressed in actual number of new cases at each date of observation, and the beetle prevalence is given in percentages, 100 per cent representing the maximum number of beetles for each brood.

Similar records also were kept (1916) of beetle and wilt prevalence in two experimental fields at Giesboro Point, D. C. (fig. 5; XI, XVI), with records over a part of the season in several other fields in the same locality; and records for two other fields at East Marion, Long Island, were made.

A detailed discussion of the beetle and wilt records follows:

In Fields I and II (figs. 1 and 2), East Marion, 1915, the striped-beetle curve shows that the maximum covers several days during the last of June and first of July, while the maxima of the corresponding wilt curves cover the last few days of July, almost one month later. In Field III, though planted only three days after Field I, the striped beetles were much later in appearing. Here the maximum of the beetle curve is about the first of August and the maximum of the wilt curve the last few days of August, almost a month later. Fields I and III were less than a quarter of a mile apart; in fact, both were a portion of one larger field, so that the meteorological conditions were similar, yet the wilt curves in the two cases were approximately a month apart. In Fields I and II the maxima of the wilt curves came just before the greatest rainfall of the season, while in Field III the reverse was true. No definite relation between the wilt and the temperature or rainfall could be detected in any case. Thus in these three fields wilt prevalence bore a clear and definite relation to striped-beetle prevalence rather than to weather or to time of planting.

At East Marion (L. I.), N. Y., in 1916 (figs. 1 and 3) the maximum of the striped-beetle curve for the first brood occurred about June 26, while for the corresponding Fields, II and IIa, the wilt-curve maximum occurred, respectively, around July 27 and 29, about one month later. As shown in the graph, downy mildew (*Pseudoperonospora cubensis*) appeared early in August and during the rest of the month, while the summer brood of striped beetles was making its appearance, gradually destroyed the vines in our experimental fields. No evidence of another brood was

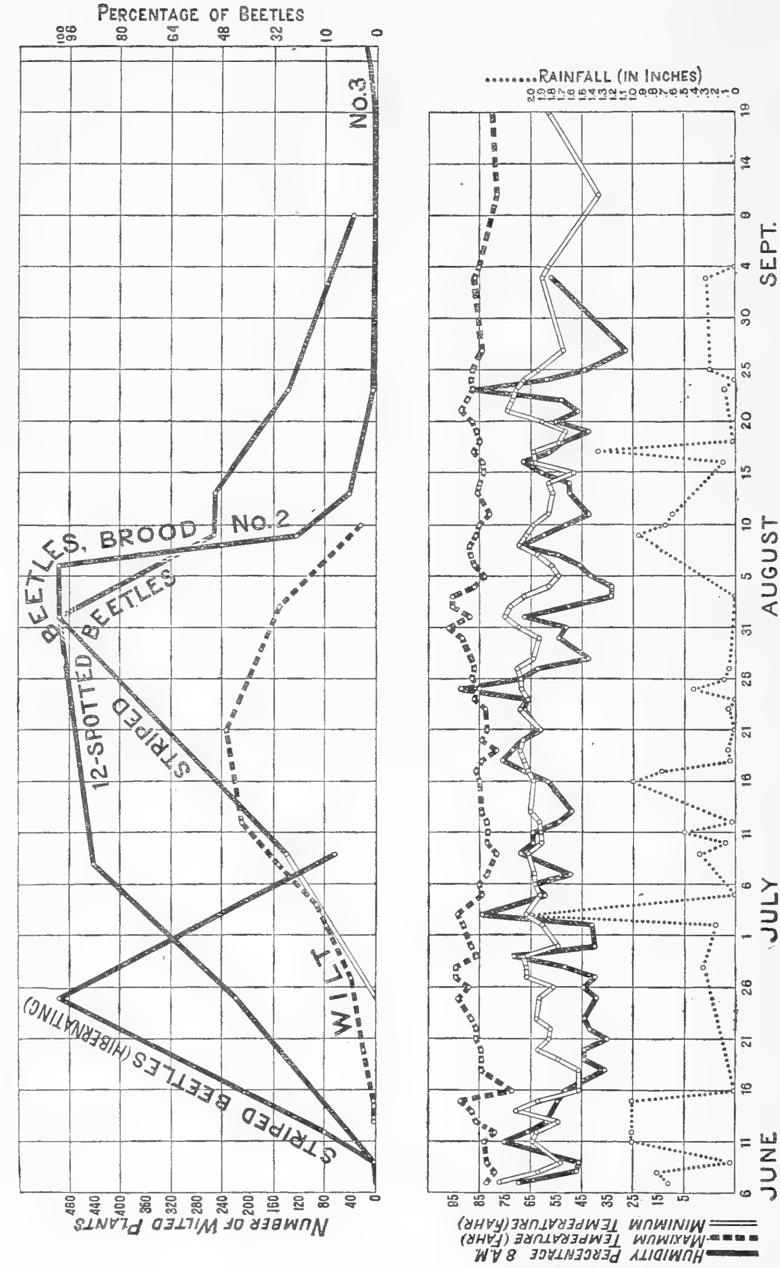

FIG. 4.—Comparison of the prevalence of wilt with that of striped cucumber beetles and with meteorological phenomena in an experimental field, Tuxedo, Md., 1917. (The curve of 12-spotted cucumber beetles is also shown. In all the beetle curves, maximum prevalence is indicated at 100 per cent, regardless of the actual numbers present.)

found in this locality. Referring to the beetle curve for the hibernating brood (fig. 3), it will be seen that on June 14 and again about June 21 there was a sudden drop in the number of striped beetles. On looking over the daily notes after plotting this curve, it was found that on June 13 the beetles were so numerous as to threaten total destruction to the young plants, and an application of a dust insecticide and lime mixture was made to all the plants in the field. Just before the second drop in the curve the first Bordeaux and lead-arsenate spray treatment of the season had been carried out, and in addition the same insecticide had been applied to all control plots. At the same time that the number of beetles decreased in Fields II and IIa a decided increase was noted in Field IV, about a quarter of a mile distant. In Fields II and IIa the maximum wilt came just after a period of heavy rain and high humidity, while in Field II and one other field during 1915 the maximum wilt came just before the period of heaviest rainfall and after a period of comparatively low humidity and rainfall. Again the relation between beetle and wilt curves holds, the one following the other at an interval of about one month.

During the same season (curve not plotted) records of the number of beetles and the amount of wilt were also kept for two other experimental fields in East Marion. In Field I (fig. 1) the maximum of the beetle curve occurred about June 28 and that of the wilt curve about August 1. In Field IV the maximum of the beetle curve occurred near June 26 and the wilt maximum about July 27.

During the season of 1916 the records at Giesboro Point, D. C. (fig. 5), showed this same relation. In Field XI, planted about April 25, the maximum of the first brood of beetles occurred June 12, while the maximum of wilt prevalence came exactly one month later. In another of our experimental fields (XVI) the maximum of the beetle curve came between June 15 and 20, while the corresponding wilt-curve maximum occurred about July 21. Here the first planting was made April 25, but only a few seeds came up and most of the vines were from a second planting made May 21. The month preceding the period of maximum wilt prevalence had been very dry, with only light showers, but this period was immediately followed by several days of heavy rain, during which time the downy mildew obtained a foothold, so that after July 28 no additional wilt records could be kept.

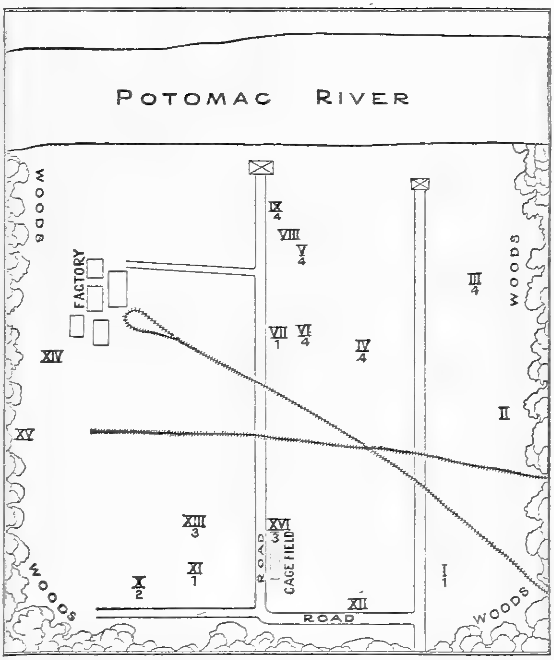

FIG. 5.—Map of a portion of Giesboro Point, D. C., where wilt-sequence records were kept during the spring of 1916. The roman numerals show the location of the fields; the arabic numerals show the sequence of the wilt.

Partial records in this locality were also kept for about a dozen other fields of cucumbers, cantaloupes, and varieties of summer and winter squashes. While the data for complete graphs of both beetles and wilt are not available in these last cases, the portions of the curves made show the same relations as in the instances where complete records were kept. In general, the earlier planted fields developed their maximum wilt prevalence before the later planted fields, but with a few notable exceptions. Thus four out of six cucurbit fields planted between April 25 and May 1 developed their maximum wilt between June 23 and 30, while four out of five fields planted after the first of May (mostly between May 15 and 20) developed their maximum wilt about the middle of July. Of the exceptions, one field planted April 25 and one planted May 15, each gave their maximum wilt on July 5. Reference to the notes in these cases showed the striped-beetle maximum in both fields to have come early in June. Furthermore, one cucumber field planted April 20 to 25 had its maximum beetle prevalence June 12, and its maximum wilt came July 12; another cucumber field planted May 21, with beetle maximum between June 15 and 20, had its wilt maximum July 21. While wilt prevalence usually reached its maximum first in the earliest planted fields, there were these instances where it did not, and in these exceptional cases it was found the beetles had been late in making their appearance. Thus again the wilt prevalence has followed the striped-beetle prevalence rather than the time of planting or the weather conditions.

Finally, during the season of 1917, careful counts were kept of beetle and wilt prevalence (fig. 4) in our experimental field near Tuxedo, Md. Here the hibernating brood of striped cucumber beetles reached its maximum numbers June 25, while the wilt in this field of 1½ acres reached its greatest prevalence July 21. A period of heavy rains preceded and followed the time of maximum wilt prevalence, and rain was fairly well distributed throughout the season. About August 10, the cucumber plants reached maturity and died. The field was replanted, but only about one-fifth of the seeds germinated. The young of the summer brood of striped beetles fed freely on these scattered seedlings, but no wilt was found. The young of a fall brood of striped cucumber beetles began to appear about the middle of September, but at this time all our cucurbits were either ripe or dead, so that their relation to the wilt was not observed. No attempt was made to determine the number of broods of the 12-spotted cucumber beetles, but the curve shows their general prevalence throughout the season. Except for short periods between the broods of the striped beetles, *they were at no time present in as large numbers as the striped species.*

As will readily be seen from the preceding statements and from a comparison of the three sets of graphs (figs. 2 to 4), the wilt curves always bear a definite relation to the beetle curves, approximately one month occurring between the maxima of beetle and wilt curves. Wilt prevalence does not in these cases show any relation to time of planting, humidity, or rainfall, and little or none to temperature.

About one month appears in all these sets of curves between the maxima of beetle and of wilt prevalence. Yet cucumber plants *usually* wilt within less than two weeks after they are inoculated, and the results of a spray test (cf. p. 39) in one of the fields where these beetle and wilt records (fig. 3) were kept show that the greatest number of infections actually did take place within the preceding 2-weeks period. Why, then, are the maxima of the beetle and wilt curves so far apart? Collating all our experimental data and observations concerning beetle and wilt relations, the explanation appears to be that early in the spring only a very small percentage of the beetles are wilt carriers. As the season advances and larger and larger numbers of cucurbit plants become wilted a correspondingly larger and larger number of beetles have the opportunity to feed on diseased plants and so to become possible wilt carriers. Thus the maximum number of actual wilt carriers comes not simultaneously with the maximum beetle prevalence, but after that maximum; that is, at some time during the downward progress of the beetle-prevalence curve.

STOMATAL INFECTION.

Since the last publication on the subject by the writers[1] further attempts at stomatal infection have given uniformly negative results. Unless the epidermis is wounded and the wilt organism introduced, infection apparently never takes place.

SOIL INOCULATIONS.

As reported in a previous article,[2] the only cases in which we have been able to transmit wilt through the soil have been those where heavy tap-water suspensions of virulent bacteria had been poured directly around the roots of potted plants. In these cases sufficient water was used so that it would immediately percolate through the soil to the roots, and some of the plants were root pruned on one side. Only a small percentage, even of the root-pruned plants, became infected, and examination of the roots of nonroot-pruned plants which had wilted usually showed injuries from transplanting, from nematodes, or from other causes.

During 1916 and 1917 several further series of soil inoculations on potted cucumber plants were carried out in a similar manner. The virulence of the heavy tap-water suspensions of the bacteria was established in each case by needle-puncture inoculations made just before pouring into the soil. Briefly, the results are as follows:

March 31, 1916. All had been recently transplanted. (1) Not root pruned, 36 pots, 2 plants to a pot; 22 per cent wilted. (2) Root pruned, 24 pots, 2 plants to a pot; 25 per cent wilted.

April 19, 1916. All had been transplanted. (1) Not root pruned, 30 pots, 2 plants to a pot, 23 per cent wilted. (2) Root pruned, 18 pots, 2 plants to a pot; 39 per cent wilted.

April 19, 1916. All these plants were grown in the pots without transplanting. (1) Not root pruned, 36 pots, 2 plants to a pot, 2.8 per cent wilted. (2) Root pruned, 24 pots, 2 plants to a pot, 29 per cent wilted.

December 7, 1916. All these were old plants and not recently transplanted. (1) Not root pruned, 4 pots, 1 plant to a pot, no wilt. (2) Root pruned, 4 pots, 1 plant to a pot, 50 per cent wilted.

December 7, 1916. All these were young plants recently transplanted. (1) Not root pruned, 27 plants, 3.7 per cent wilted. (This plant showed the roots badly gnawed. Examination of the roots of 8 of the nonwilted plants failed to show any root injury.) (2) Root pruned, 9 plants, 55 per cent wilted. (Examination of the roots of the 4 nonwilted plants failed to show root injury. In running a knife into the soil the main roots at least must have been missed.)

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[1] Rand, F. V., and Enlows, Ella M. A., 1916. Op. cit., p. 425.
[2] Rand, F. V., and Enlows, Ella M. A., 1916. Op. cit., p. 423.

April 11, 1917. Not root pruned, but recently transplanted, and soil suspension poured on base of stem as well as into soil around plant; 72 plants, 61 per cent wilted.

April 13, 1917. Not root pruned, but recently transplanted; 114 plants, 25 per cent wilted.

May 27, 1917. Not root pruned, not transplanted; 20 plants, 2 plants to a pot, none wilted.

Averaging the percentages of infection for all these series of soil inoculations to potted plants, it is found that 17 per cent of all the nonroot-pruned plants became infected, as against 39 per cent of infection among the root-pruned plants. But most of the cucumbers had been recently transplanted, and where in these cases examinations were made of nonroot-pruned wilting plants, root injuries of some sort were usually found. In those cases where the plants had neither been root pruned nor recently transplanted, infections even in the presence of such enormous numbers of bacteria were rare. This evidence, together with that given in other portions of this bulletin, points to the conclusion that the wilt organism does not gain access to the uninjured roots of cucurbits and that under field conditions no infections at all come from the soil.

VIABILITY OF THE WILT ORGANISM IN THE SOIL.

In order to determine how long the wilt organism would remain viable in ordinary garden soil, heavy tap-water suspensions of the bacteria were poured on the soil in one corner of a greenhouse bed. Then at intervals tap-water suspensions of the upper 2 to 4 inches of this soil were made and sprinkled over the needle-punctured leaves of young potted cucumber plants. In no case did any of these plants contract wilt, although the control plants inoculated by needle punctures with the original suspensions promptly succumbed to the disease. Details of these experiments follow:

December 4, 1916. Eight plants were inoculated within one-half hour after pouring the bacterial suspension on the soil. Up to December 30 no wilt had occurred on any of them, although all plants inoculated with the original suspension used in inoculating the soil became infected.

January 8, 1917. Within one-half hour after pouring the bacterial suspension on the soil the thin mud thus made was directly transferred to all the leaves of eight young cucumber plants and numerous needle pricks made into each leaf. At the same time the tips of two other young plants with several pricked leaves were inverted in some of the water suspension of soil and bacteria, left in it for 24 hours, and then held for observation. Three days after the soil inoculation another thin-mud suspension from it in tap water was made and sprinkled over the pricked leaves of 13 young cucumber plants. All these plants were under observation for several weeks, but not a single case of wilt occurred. The control plants inoculated with the original bacterial suspension all wilted.

January 18, 1917. Soil-suspension inoculations into the pricked leaves of eight young cucumber plants, made one-half hour after inoculating the soil, all gave negative results. The control inoculations from the original suspension all gave positive results.

March 26, 1917. Some soil in a greenhouse bed was inoculated to the consistency of thin mud with a thick, milky suspension of wilt bacteria. After 12 hours 10 young cucumber plants were thoroughly wet down with a tap-water suspension of this soil and the leaves all needle punctured. No wilt occurred in any case, although the six control plants inoculated with the original bacterial suspension promptly wilted.

For some reason the bacteria placed in our greenhouse soil have not retained their power to infect. This might be due to a too-great dilution of the bacteria, to their adsorption by the soil particles, or to injury or death from other antagonistic organisms, or from toxic substances in the soil. This phase of the problem is being further investigated.

DO INSECTS BRING WILT FROM THE SOIL TO THE PLANT?

Although cucurbit plants do not contract wilt directly from the soil under field conditions, the question was raised whether the wilt organism might not be brought up from the soil on the bodies of insects and introduced into wounds made by insects or other agencies. Such a method of infection is against conclusions drawn from careful field observations during several seasons in many localities. Furthermore, insects other than the Diabroticas have in all our tests failed to transfer the disease; and mechanical injuries to the vines resulting from storms, cultivation, and other causes in fields badly infested with wilt during the current and preceding seasons have shown no relation to wilt infection. However, for the sake of clearing up this point definitely, the following greenhouse and field experiments were made.

October 15, 1916. The soil in a large greenhouse bed was divided into eight compartments, each approximately 4 feet square, with solid board partitions at the base extending 2 feet into the soil and each compartment covered with 18 mesh wire netting over a skeleton frame (Pl. III). The soil was sterilized for one hour at 15 pounds steam pressure by the steam-pan method, to kill all insects present. This sterilization was repeated one week later to make the result doubly sure, and care was taken that every part of the soil was reached. The soil was allowed to stand three weeks and was then raked over with sterilized tools and thoroughly wet down in seven compartments with a heavy tap-water suspension of *Bacillus tracheiphilus* from 1-week-old beef-agar cultures grown in large flat culture flasks. The soil in compartment 4 was sprinkled with tap water only and held as a control. In the inoculation suspension 10 different isolations of the wilt organism were used. Before inoculation of the soil the virulence of this suspension was proved by needle-prick inoculations in the leaves of 13 potted cucumber seedlings, all of which promptly wilted. Arlington White Spine cucumber seeds were then sown in the soil still wet with the bacterial suspension. Insects were then introduced as follows:

Compartment 1. A total of 116 striped cucumber beetles previously shown to be free from wilt by feeding on cucumber plants which did not subsequently contract the disease.

Compartment 2. Miscellaneous insects (species of flies, lady bird, etc.) and angle worms and wireworms.

Compartment 3. Squash bugs.

Compartment 4. Control, without soil inoculation or insects.

Compartment 5. Nematodes (*Heterodera radicicola*). Two buckets of soil from around nematode-infested tomato plants were thoroughly mixed with the soil, and in addition the infested roots and stems of several tomato plants were cut up and raked into the soil.

Compartment 6. Seven wilt-free 12-spotted cucumber beetles.

Compartments 7 and 8. Control on insects. Soil inoculated with *Bacillus tracheiphilus*, but no insects introduced.

Until the seeds had germinated, the beetles were fed on cut stems and leaves of healthy cucumber plants introduced into the compartments on pieces of heavy manila paper to keep the pieces from possible contamination by the soil.

Eight days after sowing the seed the soil was reinoculated in the same manner as before with a suspension of *Bacillus tracheiphilus* proved virulent by needle-prick inoculations into 31 potted cucumber plants, all of which wilted.

On December 4, 1916, the young cucumber plants in all the compartments were thinned out and the soil loosened. In compartment 1, 85 plants showed beetle gnawings on the true leaves, as did also several plants in No. 6.

Again on December 7 the soil was inoculated with *Bacillus tracheiphilus* as before, using great care, however, to prevent the liquid from coming in direct contact with the plants. All control plants inoculated from this fluid by needle puncture wilted.

About the middle of December, 25 striped beetles were counted feeding on the plants in No. 1, and 4 more wilt-free 12-spotted beetles were added to No. 6, where they were later seen feeding.

This experiment was under almost daily observation from the time the seeds were planted (November 15, 1916) until January 11, 1917, and not a single case of bacterial wilt or anything suggesting it occurred during the whole time in any of the compartments. At this date the first crop of plants was pulled, and cucumber plants grown in sterile soil in pots were transplanted to the bed cage—six hills of three to four plants each to every compartment. The soil was then reinoculated with *Bacillus tracheiphilus* as before. Up to January 29 the plants were fed upon by both species of cucumber beetles, but no wilt had occurred in any section of the cage. Six more small plants were then set out in compartment 1, cucumber seeds planted in all the compartments, and the soil reinoculated with *Bacillus tracheiphilus* as before. Up to February 9 no wilt had appeared, although plants in Nos. 1 and 6 had been fed upon, and Diabroticas were still alive in both compartments. Powdery mildew was now getting bad, so all plants in the bed were pulled and fresh plants grown in sterilized soil were set in each compartment. There were now six beetles in compartment 1 and one beetle in compartment 6. One week later the soil was reinoculated as before and, as in each preceding case, the virulence of the bacterial fluid was proved by needle-puncture inoculations. At this date 6 pots of cucumber plants were placed in compartment 1 and 13 in compartment 6 and left for five days, at which time the leaves on every plant had been gnawed by the beetles. The plants were then removed for observation. Three more potted plants were then placed in compartment 1, and after the leaves had been gnawed these also were removed and held for observation. No wilt occurred on any of these plants.

On February 17 and again on March 8 the soil was all respaded and each compartment set to plants grown in sterile soil and the soil in the bed reinoculated with *Bacillus tracheiphilus* as before. In no case did a single plant in any of the compartments contract wilt, although the suspensions used in inoculating the soil were virulent, as shown by needle-punctured control inoculations.

This set of experiments was discontinued about March 25, 1917, and the whole cage was taken up and removed to one of our experimental fields near Tuxedo, Md., where with the slight variations noted below the experiment was repeated.

Compartment 1. Control. Soil not inoculated, but cucumber seeds sown.

Compartments 2 and 3. Soil inoculated with a well-water bacterial suspension from 4-day-old beef-agar cultures and sown to cucumber seeds while the soil was still moist.

Compartment 4. A large number of cucumber vines freshly wilted from pure-culture inoculation were buried in the soil just before sowing cucumber seeds.

Compartments 5 and 6. Controls. Not inoculated, but cucumber seeds sown and wilt-free striped and spotted cucumber beetles introduced.

Compartments 7 and 8. Soil inoculated and planted to cucumber seed as in Nos. 2 and 3, but in these cases the soil had been drenched with formalin (1–320) two weeks previously to kill any insects and insect eggs and pupæ present in the soil.

In due season the seeds germinated, and the plants in all the compartments continued healthy and vigorous. On June 15 the soil was again inoculated with *Bacillus tracheiphilus* as at first, and wilt-free striped and spotted cucumber beetles were introduced into all the compartments except the control, No. 1.

Up to June 27 no wilt had occurred anywhere in the compartments and all the plants were pulled; the soil was reinoculated as before, immediately replanted with cucumber seed, and two days later more wilt-free cucumber beetles were added.

Again on July 23 the soil was very heavily reinoculated. The cucumber plants were now in full bloom. No wilt had yet appeared.

On August 22 the soil was again inoculated. Beetles were present in all the compartments and the vines had been fed upon freely. The cage was under constant observation up to September 15, but at no time did any wilt develop.

In this same field similar tests were carried out at varying intervals throughout the season, using three of the large cloth-covered cages (Pl. II, fig. 1). In two of these cages the soil was inoculated by bacterial suspension and in the third by burying 24 wilted vines in the soil about 1 inch below the surface. In the latter case cucumber seeds were planted directly among these wilted vines. Wilt-free beetles were added to each cage and the soil was inoculated several times during the season. No wilt developed in these cages at any time.

In all these experiments the virulence of the bacterial suspensions used was proved by needle-puncture inoculations into cucumber seedlings.

In these numerous greenhouse and field tests where the soil was heavily inoculated with virulent bacteria or when freshly wilted vines were buried in the soil and where wilt-free cucumber beetles and other insects, nematodes, etc., were introduced with the cucumber seeds sown in these soils no single case of bacterial wilt developed. These results fully corroborate the findings from careful field observations, namely, that bacterial wilt of cucurbits develops under field conditions only when introduced into the plant by human agencies or by cucumber beetles which have previously fed upon plants infected with the wilt organism.

WINTER TRANSMISSION OF WILT.

BEETLE HIBERNATION EXPERIMENTS.

As previously reported,[1] in some cases, at least, striped cucumber beetles are capable of carrying the wilt organism during six weeks' artificial hibernation in cold storage. Several similar cold-storage tests have been carried out since that report. Striped beetles both of the hibernating and summer broods were used, and the conditions of temperature and humidity were varied in different sets. However, in no case have we been able to keep the beetles alive for a longer period than six weeks.

Experiments of 1916.—It was thought possible that better success might be obtained if the beetles were allowed to hibernate under more natural conditions. Accordingly, in eastern Long Island during September and early October, 1916, about 4,000 cucumber beetles (mostly *Diabrotica vittata*) were collected, and 150 to 300 were introduced into each of 20 large wire-covered cages (Pl. II, fig. 2). These cages were 4 feet cubes, were provided with solid board bases without bottoms, and were set 15 inches into the soil. A pile of dry sticks and chips was placed in one corner of each cage, and the imprisoned beetles were fed upon wilted cucumber and squash vines until the 1st of November, at which time settled cold weather had come and all the beetles had disappeared from view.

This experiment was duplicated the same fall at Giesboro Point, D. C., using about 2,500 striped and 12-spotted cucumber beetles, the two species being caged separately. From 50 to 150 beetles were introduced into each of 15 cages provided in this case with a double covering of wire netting and fine cheesecloth. Boxes filled with hay or excelsior were placed in part of the cages and in a few cages a pile of dry chips, sticks, and bark was also added.

In the following spring cucumbers were planted in the cages in both localities, and the plants were kept under careful observation from the first appearance of warm weather until cucumber beetles had long been present in the surrounding fields. In all this time not a single cucumber beetle nor a beetle-injured leaf was found inside any of the 20 cages on Long Island or of the 15 at Giesboro Point, D. C.

During September, 1916, a supplementary test was started, using 11 pint glass jars with 2 inches of fine leaf mold in the bottom and covered at the top with fine cheesecloth. From 18 to 50 cucumber beetles were placed in each of these jars, fed upon wilted cucumber plants, and kept over winter in an open shed. Many of the beetles were still alive 38 days after imprisonment, but in the spring following all were dead.

[1] Rand, F. V., and Enlows, Ella M. A., 1916. Op. cit., p. 417.

ONE OF THE SMALL CAGES USED IN THE INSECT-FEEDING EXPERIMENTS.

Photographed by J. F. Brewer.

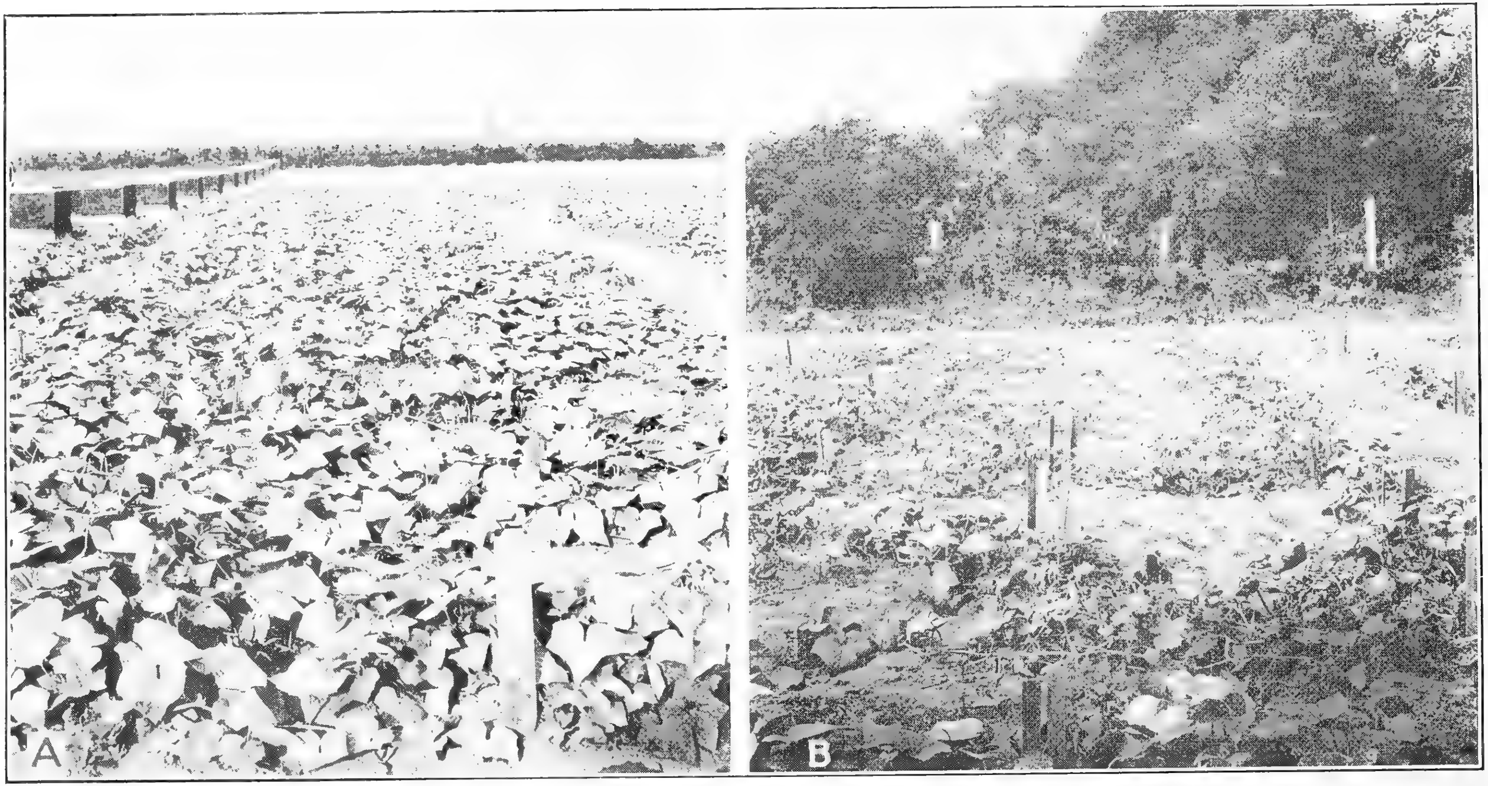
FIG. 1.—LARGE INSECT CAGES IN THE EXPERIMENTAL FIELD AT TUXEDO, MD. THE METEOROLOGICAL INSTRUMENT SHELTER IS SHOWN AT THE LEFT.

FIG. 2.—CUCUMBER SPRAY TEST PLAT NO. 11, SPRAYED WITH LEAD ARSENATE ALONE, EAST MARION, LONG ISLAND, N. Y. EACH STAKE REPRESENTS A CASE OF WILT.

Photographed by F. V. Rand.

LARGE 8-COMPARTMENT CAGE USED IN THE EXPERIMENTS RELATIVE TO INSECT TRANSFER OF WILT FROM THE SOIL.

Photographed by J. F. Brewer.



CUCUMBER SPRAY TEST AT EAST MARION, LONG ISLAND, N. Y.

Each stake represents a case of wilt. *A*, Plat No. 6, season treatment with Bordeaux and lead-arsenate mixture (2-3-50-2); *B*, plat No. 1, one of the controls, unsprayed. Photographed by F. V. Rand, August 25, 1916.

Experiments of 1917.—In August, September, and October, 1917, at Tuxedo, Md., about 5,000 of these two species of cucumber beetles were collected. Special care was taken not to injure the beetles in any way, and they were placed at once in the cages (Pl. II, fig. 1) standing in the fields where they were caught. Three species of cucurbits were growing in these cages and also corn in a few of them. Some of the cucurbits were inoculated with the wilt organism and others were left uninoculated. After the growing plants in the cages had died, squashes and other cucurbit fruits were fed to the beetles until November, 1917. A few of these cages were destroyed by winds during the succeeding winter, but in the 13 remaining intact not a single beetle appeared in the spring of 1918. It might be added, however, that in one of these cages into which several squash lady bird (*Epilachna borealis*) had been introduced the preceding fall, three live individuals were found in May, 1918.

These attempts at hibernation of wilt-fed cucumber beetles under experimental conditions have been rather discouraging, since, so far as ascertained, none have lived longer than six weeks under the hibernation conditions used.

On the other hand, striped cucumber beetles collected at the same time and place for the direct wilt-transmission experiments in the warm air of the greenhouse have frequently been kept alive and active in small cages (Pl. I) for three to five months, and in two cases for more than six months (Oct. 4, 1916, to Apr. 28, 1917). These beetles were fed upon potted young cucumber plants which were frequently changed. and they were under almost daily observation.

DO THE WILT BACTERIA WINTER OVER IN THE SOIL?

Experimental carrying of the wilt organism through the entire winter by the beetles has failed, on account of our inability to keep the beetles alive for that length of time under the hibernation conditions given. However, the problem has been attacked from other angles and some further evidence has been accumulated to show that the striped cucumber beetle may be a winter carrier of *Bacillus tracheiphilus*.

In eastern Long Island the previously reported[1] cage experiments were repeated during the summer of 1916. In the original experiments (1915) 50 large, wire-covered cages (Pl. II, fig. 2) were set in two fields where during the preceding season about 75 per cent of the cucumber plants had been infected with wilt. In September, 1915, and again in May, 1916, the soil in one-half of these cages was heavily inoculated with well-water suspensions of tested virulent wilt bacteria. No beetles were introduced, and not a single

[1] Rand, F. V., 1915. Op. cit.

case of wilt occurred throughout the summer of 1916 in the cucumbers growing in this artificially infected soil in any of the 50 cages, although, as in the preceding season, the disease was abundant on the plants outside the cages.

At Giesboro Point, D. C., a second experiment, using 20 similar cages, was carried out during 1916 on land planted to Hubbard squashes the preceding season. Wilt was very prevalent in these vines during the fall of 1915, as verified by personal observations and by pure-culture isolations. Many hills bearing wilted vines were marked at this time, and 12 of the cages were set directly over such hills. A wire netting slightly coarser (16 meshes to the inch) than that used in the Long Island experiments was employed for these cages, with the result that some of the smaller beetles, especially of the second brood, gained entrance. Until the first of July all of the cages were gone over every day except Sunday and any beetles or gnawed leaves found within were removed. Wilt in this vicinity first appeared on June 3 in four near-by fields not in cucurbits the preceding season and on June 13 in the cucumbers around the cages.

On July 5, over a month after the first appearance of wilt in this vicinity, a gnawed leaf which had been overlooked in one of the cages began to wilt around the points of injury. With the appearance of many small beetles of the second brood in July it became impossible to keep them entirely out of all the cages. On that account, after July 25, wilt occurred in single plants in 4 other cages out of the 20. In all these cases striped cucumber beetles had gained entrance, and the first leaves to wilt were those showing beetle injuries. There was no infection from the soil in any case, but direct and positive evidence of infection from cucumber-beetle injuries and absence of infection in the absence of such injuries.

SPRING SEQUENCE OF WILT.

In addition to the cage experiments during the early part of the season of 1916, a complete record was kept of the first appearance and spread of bacterial wilt of early cucurbits in all the field and garden plats in these two localities.

At East Marion, Long Island, the area selected comprised the land between Long Island Sound and Greenport Harbor and extending about 2 miles east and west. (Fig. 1.) No wild cucurbits occurred within at least 10 or 15 miles of this locality.[1]

A careful inspection on June 8, 9, and 22 of all cultivated cucurbits within this area gave no evidence of wilt.

The first wilt of the season was found on June 29 on a cucumber plant (fig. 1) in our experimental Field IV, planted May 24, 1916, and not in cucurbits the preceding season. The plants were just breaking through the ground on June 5, but on account

[1] Rand, F. V., and Enlows, Ella M. A., 1916. Op. cit., footnote 2, p. 419.

of rather cool weather during early June they had at this time (June 29) attained a height of only 2 to 4 inches with two to four true leaves developed.

The following day, June 30, seven cases were found in two half-acre commercial fields (V) of cucumbers planted May 15 (not in cucurbits in 1915) and 19 cases in a large garden plat of cucumbers and squashes (XII) likewise planted May 15 (possibly in cucurbits the preceding year).

The next cases of wilt were found July 11 in our experimental Blocks II and IIa (IIa was not in cucurbits in 1915). These blocks were first planted on May 8, but on account of cold, damp, weather and a consequent poor stand they were replanted June 13.

Cucurbits were planted in experimental Blocks I and III on June 21, and wilt first developed here July 20.

In all these instances wilt started from beetle-injured leaves. Subsequent cases developed in similarly injured plants and more or less in widening circles around the original centers.

The record at Giesboro Point, D. C., covered an area approximately one-half by three-quarters of a mile in extent, bounded on one side by the Potomac River and on three sides by woods. (Fig. 5.)

Up to June 1, 1916, no wilt had appeared within this area. At the next date of observation, June 3, one case of wilt was found in a cantaloupe field planted May 10, one case in a crookneck-squash field planted about May 1, and three and six cases, respectively, in two cucumber fields planted April 20 to 25. At least three of these fields were not in cucurbits the preceding season. Pure cultures of *Bacillus tracheiphilus* were obtained from several of these plants.

On June 6 one plant began to wilt in a cymling field planted April 20 to 25 and not in cucurbits during 1915.

On June 13 seven plants began to wilt in a cymling field planted about May 15 and not in cucurbits during 1915, and four cases developed in cucumber plants outside the wire-covered insect cages in the experimental field where the main part of the stand was planted May 31. Wilt was very prevalent in this field during 1915.

At the time of the next observation, June 23, wilt was becoming rather prevalent in all the fields where wilt had occurred before the middle of the month, and many cases were also found in four other fields.

Observations throughout the season on wild cucurbits (*Sicyos angulatus*) growing abundantly along the Potomac shore failed to show any signs of bacterial wilt, although a few striped cucumber beetles were now and then found feeding upon the leaves. On two occasions a slight but general wilting was noted during a hot sunny day on plants growing in the sand high up on the shore. The wilting was plainly due to excessive transpiration in a dry soil. However, plates were poured from several of these plants and a microscopical examination also was made. There was in no case any evidence of bacterial invasion.

During the spring of 1917 a similar set of observations was made in a locality near Tuxedo, Md. On account of the press of other work the records were not quite as complete, but the results were entirely in line with those obtained in the two preceding localities.

It should be noted with regard to the bacterial wilt in these three localities that in all cases the leaves first showing wilt in the spring had typical cucumber-beetle injuries, that the wilt had plainly started from these injured points, and that in many of the fields such beetle injuries had not at this time become general.

There is a tendency for wilt to spread in groups around the plants first developing the disease, and in all observed cases it always starts from beetle-injured plants. The facts that a careful record was kept of all cucurbits in these localities and that the first wilt to appear was from beetle injuries on the earliest plantings of the season preclude the possibility of a transfer of the disease from previously wilted cucurbits of the current season. These results, added to the data presented in our previous papers, negative the possibility of transmission of bacterial wilt of cucurbits through the soil from season to season and give strong circumstantial evidence in favor of the cucumber beetles as winter carriers.

Until the striped or 12-spotted cucumber beetles can be hibernated successfully in considerable numbers and under experimental conditions, absolute experimental proof that these insects are winter carriers can not be obtained. However, it would appear from the evidence given that either the beetles must have carried the wilt organism over winter or must have brought it directly from previous cases of the current season. The second assumption is eliminated so far as cucurbits are concerned by the facts that in neither locality were cucurbits grown under glass, that our observations covered a considerable territory, and that the wilt appeared on the very earliest plantings of the season only after the plants were bitten by the beetles. In one locality no wild cucurbits were present within at least 10 miles.

Apparently the only loophole remaining is the possibility that the organism may live over winter in some perennial noncucurbitaceous host. In his early work upon this organism, Dr. Erwin F. Smith obtained infections by pure-culture inoculations on various species of Cucumis and Cucurbita and on *Benincasa cerifera*, *Sicyos angulatus*, and *Micrampelis lobata*, and failed to infect or obtained only local injury on the following cucurbits: *Melothria scabra*, *Cucumis erinaceus*, *Luffa acutangula*, *Momordica balsamina*, *Lagenaria vulgaris*, *Trichosanthes cucumeroides*, and *Apodanthera undulata*.[1] He states further:

> "Inoculations into noncucurbitaceous plants such as *Solanum tuberosum*, *Lycopersicum esculentum*, *Datura stramonium*, *Passiflora incarnata*, *Vigna catjang*, *Nicotiana tabacum*, *Pyrus orientalis*, and *Hyacinthus orientalis* yielded only negative results. The disease is not known to occur outside the Cucurbitaceæ, and probably many species of plants within the limits of this family are not subject to it."

The present writers have no data concerning the possible occurrence of this disease outside the Cucurbitaceæ.

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[1] Smith, Erwin F. Bacteria in relation to plant diseases, v. 2, p. 209. Washington, D. C., 1911. (Carnegie Inst., Washington. Pub. 27, v. 2.)

SEED TRANSMISSION.

Our earlier experiments relative to seed transmission [1] all gave negative results. One further planting of seeds from a wilting cucumber vine gave healthy plants which at no time showed signs of wilt. Numerous plantings have also been made with cucumber seeds soaked in heavy tap-water suspensions of virulent wilt bacteria immediately before sowing. These tests likewise all gave negative results.

RELATION OF THE WILT BACTERIA TO CUCUMBER BEETLES.

SUCCESSIVE INFECTIONS.

The objection has been raised that it would be impossible for the cucumber beetles to feed for several weeks in the early spring upon noncucurbitaceous plants and yet infect cucurbits when they appeared above ground. It is a well-known fact that these insects are rather omnivorous and in the absence of cucurbits will feed on a wide range of host plants. In a locality where cucurbits are planted late in the season the beetles feed for some time on other vegetation. If the wilt organism is carried only on the mouth parts or other external portions of the body, one might think that after feeding two or three weeks on plants not infected with cucurbit wilt none of the bacteria would be left. However, early spring infection *does* occur, and the following experiments were designed to throw further light on this question.

The small cages used in these experiments (Pl. I) were covered with 18-mesh wire netting, and the bases and joints were made insect proof. After allowing the beetles to feed on the plants, the latter, unless otherwise stated, were removed and held for observation in similar cages free from insects. The details of these experiments are as follows:

In July, 1915, at East Marion, Long Island, several striped cucumber beetles were inclosed over a hill containing wilting young cucumber plants and were allowed to feed on them for five days. The beetles were then removed and allowed to feed for 24 hours each on three healthy and uninjured young cucumber plants successively caged with them. These three plants were then kept under observation in a cage free from beetles, and between the seventh and tenth days all had shown evidence of wilt. The cut stems showed the typical, stringy ooze, and microscopical examination showed the xylem elements to be full of bacteria. As no culture media were at that time available, isolations were not attempted.

No further attempts of this kind were made until the following year (Sept. 26, 1916), when several striped cucumber beetles were fed for three days on plants wilted from pure-culture inoculations. The diseased plants were then removed and the beetles allowed to feed 5 and 15 days, respectively, on two large potted cucumber plants successively introduced. The plants were afterwards kept under observation for 27 days, but no wilt developed in either case.

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[1] Rand, F. V., and Enlows, Ella M. A., 1916. Op. cit., p. 424–425.

Nine striped beetles were fed constantly on wilted cucumber plants from January 7 to February 12, 1917. On the latter date all wilted plants were removed from the cage (No. XXII) and from then until March 10 they were fed on healthy young cucumber seedlings which were so small that the leaves were entirely consumed. On March 10 the three beetles left alive were caged with a large potted cucumber plant grown in a greenhouse free from wilt. Two weeks later one beetle-gnawed leaf was found wilting and after three weeks nearly the whole vine was involved. *Bacillus tracheiphilus* was isolated from this plant and tested by successful inoculations into cucumbers. The cage used for this test was covered both by wire netting and cheese cloth, and had not been used for beetles since the preceding fall.

(Cage XXIV.) From January 11 to February 5, 1917, 25 striped beetles were fed on wilted cucumber plants, then all diseased plants were removed and until February 26 the beetles were fed on very young cucumber seedlings, which were completely riddled, as in the preceding test. At the latter date a large potted cucumber plant was placed in the cage and left for three days, after which it was removed and held for observation. On March 10 this plant was wilted and the vascular system was plugged with the typical stringy masses of bacteria. No isolations were made from this plant.

(Cage XVIII.) Wilted cucumber plants from pure-culture inoculations were fed to three striped cucumber beetles on January 25, 29, and February 8. All wilted plants were removed on February 16 and a healthy young cucumber plant was introduced. Two days later this plant was removed and a second introduced, and so on until the beetles had been allowed successively to feed on four healthy plants. On February 19, plant No. 1 was starting to wilt around the beetle injuries on one leaf. Six days later this plant was showing wilt on several leaves and plant No. 3 was starting to wilt around the gnawed places on several leaves. On March 1, Nos. 1 and 3 were entirely wilted and No. 4 was starting; plant No. 2 showed no signs of wilt. However, the leaves on this plant were scarcely gnawed at all by the beetles. Isolations were made from plant No. 4 on March 1 and inoculations from this source to six cucumber plants gave typical wilt in every case.

(Cage XVIII.) On March 20, 1917, a wilted cucumber plant was fed to the same three beetles, and on March 28 it was removed and a healthy plant introduced. Two days later this was removed and a second one introduced. On April 13, plant No. 1 showed typical wilt, but No. 2 remained free from the disease.

This last experiment was duplicated on the same date in two other cages (XIII and XXI), but in these cases neither of the two plants contracted wilt.

(Cage XXII.) On the same date (March 20, 1917) wilted cucumber plants from pure-culture inoculations were fed to several striped cucumber beetles. On March 28 these plants were removed and a healthy plant introduced. Two days later, plant No. 1 was removed and a second plant introduced. Both plants contracted wilt from the beetle injuries and on April 13 were wilted throughout and dying.

Plant No. 2 was allowed to remain in the cage with the beetles. On April 28 the plant had long since died, but one beetle was found still alive in the cage and a healthy cucumber plant was introduced. On May 7 two leaves had started to wilt next to the margins, where they had been slightly gnawed. The beetle had died since the last preceding observation. The wilt was a typical case, and the vascular bundles of the leaf petioles were filled with bacteria.

From the results of these "successive infection" tests it is demonstrated that striped cucumber beetles are sometimes capable of successively infecting three or more healthy cucumber plants after one initial wilt feeding and that after one such feeding they may in some cases in the active state retain their infecting power for over three weeks.

DISSECTION EXPERIMENTS.

It is clear from the foregoing that striped beetles in the active state are sometimes capable of harboring the wilt organism for considerable periods of time. With the idea of determining in what part of the body the bacteria are carried, the following beetle dissection experiments were carried out.

Six 12-spotted cucumber beetles were fed for three weeks on wilted cucumber plants in pots and finally for five days on cut stems and leaves of wilted plants. After this last feeding (Aug. 8, 1917) the heads and legs of the beetles were removed separately with sterile instruments. Then the anal region was cut off with a hot scalpel, and the intestinal contents were carefully squeezed out with sterile instruments on a sterile Petri dish, using care that none of the contents should come in contact with the exterior of the insect body. Young potted cucumber plants were then inoculated separately with heads and mouth parts, legs, intestinal contents, and reproductive systems. In each case the body parts named were pricked into the young leaves without moistening the surfaces. Five days later one leaf inoculated with intestinal contents had started to wilt. After two days more, wilt had started in one leaf inoculated with beetle legs and in two additional leaves inoculated with intestinal contents. This infection from beetle legs is not to be wondered at, as the beetles were allowed to feed on cut stems and leaves of wilted plants for several days prior to dissection. These plants had been kept throughout the test in a large 6-foot square beetle-free cage (Pl. II, fig. 1) and were entirely free from insect gnawings. A hundred or more uninoculated cucumber seedlings of the same age and variety held as controls in the same cage remained free from the disease.

On August 16, 1917, the preceding experiment was duplicated, using six striped and twelve 12-spotted cucumber beetles. Five days later one of the plants inoculated with intestines and one inoculated with legs of the 12-spotted species were found with wilt. In this case none of the plants inoculated with head parts became infected.

During the summer of 1918 four more sets of dissection tests were carried out. On June 15, after a 7-day's feeding on wilted plants, forty striped and three 12-spotted cucumber beetles were dissected as in preceding experiments, and separate cucumber seedlings were inoculated with heads and with intestinal contents. Ten of the forty striped beetles were feeding on wilted leaves when taken. The other thirty were not feeding when taken for dissection. In these cases the body parts were crushed in a drop of tap water and pricked into the cucumber leaves. In 11 days two plants and next day three more plants showed wilt starting from leaves inoculated with intestinal contents. Of these five wilted plants only one was infected from one of the ten beetles feeding on wilt when taken; the other four wilted plants were from four of the thirty beetles not feeding when taken. Cultures made from one of these plants gave *Bacillus tracheiphilus*, and all five showed typical wilt symptoms. No infections resulted from the three 12-spotted beetles.

This experiment was repeated on June 28, using 45 striped beetles. In eight days two plants were wilting from beetle-intestine inoculations and the following day two more from intestines and one from head and mouth parts. Cultures were made from the first two plants showing wilt, and *Bacillus tracheiphilus* was isolated and proved to be virulent by successful inoculations.

Sterile instruments were used and great care was taken in all these tests not to allow the intestines to come in contact with external body parts. However, in order completely to eliminate all possible source of external contamination, the beetles in the following two tests were immersed for five minutes previous to dissection in a 1 to 1,000 solution of mercuric chlorid in 25 per cent alcohol. The alcohol was added to facilitate reaching all parts of the insect body, and the solution was also constantly shaken during the exposure.

Approximately 35 striped beetles were dissected (June 29) after a 7-day feeding on wilted cucumber plants in pots, and inoculations were made to the leaves of as many cucumber seedlings by mixing the intestinal contents of each beetle in a drop of tap water and pricking the mixture into the leaves. These plants were kept in beetle-free cage with 20 or more uninoculated control plants. Two of the inoculated plants developed typical cases of wilt starting from the points of inoculation with intestinal contents.

Finally, on July 5, 1918, the last experiment was repeated, using sixty striped and thirty 12-spotted cucumber beetles and fifteen squash lady birds. All had been previously fed for 10 days on wilted cucumber plants in pots and had been treated for five minutes before dissection with mercuric chlorid and alcohol, as in the preceding test. Five plants out of the 60 inoculated with intestines of striped beetles promptly developed wilt. All these cases showed the typical stringy slime from the cut ends of the vascular bundles, and cultures made from one of these plants gave *Bacillus tracheiphilus*. Inoculations in this experiment with intestines of the other two insect species gave negative results.

These dissection experiments prove definitely that both striped and 12-spotted cucumber beetles may harbor the wilt organism in their intestinal tracts. In fact, a much larger percentage of infections took place from intestinal contents than from mouth parts, although this may have been due to the fact that the mouth parts were harder to break up and mix thoroughly with the water on the leaves. They also show that only a small proportion of the beetles gave infection from the intestines even after feeding seven days or more on wilted plants. Thus, in the two tests with 12-spotted beetles, the intestines gave infection in about 50 and 8 per cent of the individuals, respectively. In the four tests with striped beetles the proportion varied in round numbers between 6 and 12 per cent. There was very little difference in the proportion of wilt carriers among individuals taken while feeding directly on wilted plants and those not feeding at all when taken for the test.

BACTERIAL ISOLATIONS FROM BEETLES.

One attempt was made (Dec. 10, 1917) at direct isolation of *Bacillus tracheiphilus* from the intestinal tracts of wilt-fed striped cucumber beetles.

Ten individuals were fed for two weeks upon cucumber plants wilted from pure-culture inoculation. They were then dipped for several seconds into 95 per cent alcohol, for 60 seconds in 1 to 1,000 mercuric chlorid, quickly washed in sterile water, and then given five more washings of several minutes each in sterile water. The intestinal tracts were then carefully dissected out as described under "Dissection experiments," without allowing the body contents to come in contact with the surface of the beetle. The intestines in each case were crushed in sterile distilled water with a sterile glass rod and allowed to stand for 20 minutes, when four series of dilutions in beef bouillon were made. From these tubes one series of poured plates was made at once and another the next morning after the bouillon had become slightly cloudy. From most of the plates developing colonies, pure cultures of one type of bacteria (*A*) arose, which at first somewhat resembled *Bacillus tracheiphilus*. Later, on beef-agar slants, this type gave a dense, opaque, somewhat yellowish and rapidly growing colony. A second type (*B*) was constantly found in the plates poured from one set of dilutions. This isolation (*B*) more closely resembled the wilt organism, and young colonies on beef agar were at first scarcely to be distinguished. Even the rate of growth was about the same as for *Bacillus tracheiphilus*. However, old colonies are somewhat more opaque and also have a very slight yellowish cast not present in the wilt organism. The organism also produces more alkali than *B. tracheiphilus*. Inoculation tests on cucumber plants have given negative results with both these types of bacteria. Occasional colonies of other bacterial and fungus types came up on the plates, but on account of their rarity were considered as contaminations. The wild organism was not obtained.

Portions of intestines left from each beetle dissected were retained and in each case were used in inoculating a single young cucumber plant by needle puncture. One plant only out of the ten wilted, but isolation was not attempted. There were at the time a large number of other cucumber plants in the greenhouse, all of which were free from wilt, and there is little doubt that the plant in question had become infected with the true bacterial wilt.

It was thought worth while to test the types of intestinal bacteria in mixet culture with authentic isolations of *Bacillus tracheiphilus* for possible antagonism. After three weeks in mixed cultures (beef agar plus 1 per cent cane sugar) young cucumber plants were inoculated by needle punctures in the leaves; and other plants were inoculated as checks with intestinal types *A* and *B* alone and with the wilt organism alone. Of ten plants inoculated with cultures of *A* plus wilt, and of the two plants with *A* and *B* alone, none became infected; but of four plants inoculated with *B* plus wilt all contracted wilt, showing the typical stringy ooze from the cut stems and the vessels filled with bacteria. All plants inoculated with *B. tracheiphilus* alone showed wilt. The plants were under observation one month.

In another experiment using four plants with type *B* alone, four plants with the wilt organism alone, eight plants with *A* plus wilt, and four plants with *B* plus wilt, all from 2-weeks-old cultures, the results were identical—growth of *B. tracheiphilus* and infection in the presence of *B;* none in the presence of *A*.

The wilt organism itself was not isolated on agar-poured plates made from beetle intestines, but evidence was adduced that the organism was present in the intestines of one of the ten beetles used and that in the presence of cane sugar the intestinal flora of at least one beetle was not antagonistic to the wilt organism, but that in the majority of the cases the intestinal flora (type *A*) was under these conditions antagonistic to the wilt organism.

These results, while not sufficient to warrant far-reaching conclusions, suggest the possibility that a careful study of the bacterial flora of cucumber-beetle intestines will afford an explanation of the fact that only a small proportion of wilt-fed beetles are wilt carriers.

VIRULENCE TESTS.

During the interval since August, 1914, several hundred isolations of *Bacillus tracheiphilus* have been made from cucumber, cantaloupe, winter squash, crookneck summer squash, and cymling, and from an area extending from Canada to southern Georgia and Long Island to Iowa. Of these isolations from various hosts and localities, over one hundred have been carried continuously in culture for considerable periods—in some cases for nearly four years.

It was early noted by Dr. Erwin F. Smith[1] that his isolations of *Bacillus tracheiphilus* from squash would always infect cucumber, but that his isolations from cucumber usually gave no infection at all on squash and at most only a slight local wilting near the point of inoculation. It seemed possible from these results that there might be at least two true biological strains of the organism.

With a large number of isolations from different hosts and localities at hand it seemed well worth while to investigate this question further. For this purpose relative virulence tests were made of large numbers of isolations grown on the same medium and in cultures of the same age inoculated in as nearly an identical manner as possible into one of the host varieties as an indicator. Chicago Pickling cucumbers were selected as being a representative variety of one of the most susceptible host species; and in each series of inoculation tests plants 12 to 18 inches high and of like age and similar vigor were inoculated simultaneously with cultures of the different isolations. From two to eight series of these tests were made, and in each series two or more (usually two) plants were inoculated with each isolation under study. Experience showed that within a variety a fairly constant reaction was given to any one isolation of the wilt organism, provided the plants were of comparable age and vigor. Occasionally an individual plant would show a wide variation from its fellows in reaction to a particular isolation, but since considerable numbers of plants were used these comparatively rare aberrant cases did not alter the end results of the study.

In each series of tests careful observations were made of the absolute and relative progress of the disease, special attention being given to three cardinal points—(1) the number of days after inoculation when incipient wilt was noted, (2) the total number of days after inoculation required for actual wilting of the larger part of the inoculated leaf, and (3) the total time after inoculation for the wilting of the entire plant. By "incipient wilt" is meant either a slight loss of turgor without actual wilting or a slight indication of wilt immediately around the point of inoculation. For purposes of ready comparison a "virulence index" was worked out for expressing the degree of relative virulence of each isolation to the indicator used. This virulence index was secured in each instance by adding together the three cardinal points above mentioned. These figures as they stand express the relative virulence in inverse ratio, the smaller figure expressing the greater virulence. In order to show the relation more clearly, expressing the greater virulence by the larger number, the numerator "1" was placed over each of the figures so obtained

[1] Op. cit., p. 284.

and the resulting fraction reduced to a decimal. In making up the relative-virulence graphs these fractions were used in the abscissæ to express varying degrees of relative virulence between possible instant death (unity) and no infection at all (zero). For example, one isolation gave (1) incipient wilt in 4 days, (2) wilt of the inoculated leaf in 5 days, and (3) wilting of the whole plant in 11 days after inoculation. Added together, these three figures equal 20, the number used as the basis of comparison. The expression 1 over 20 reduced to a decimal equals 0.05, which is the figure taken as the final index expressing the degree of relative virulence for this particular isolation of *Bacillus tracheiphilus*. This happens to be one of the most virulent isolations found thus far in our study.

The relation in number of days between 1 and 2 and between 2 and 3 tended to be similar in the different isolations tested. That is, if the first signs of wilt appeared late a longer time usually elapsed before complete wilting than when the first signs appeared early. However, this rule was not strictly true in all cases, so it was felt that a truer comparison could be made by adding together the three cardinal points above mentioned rather than by taking any one of them alone as the basis for comparison.

In the graphs the ordinates show the number of isolations found by numerous inoculation tests to fall at any particular degree of relative virulence. In plotting the curves the average virulence index for all tests with any one isolation was in each case taken.

One hundred and three different isolations were tested as to relative virulence in Chicago Pickling cucumber, and this list included isolations from cucumber, squash, and cantaloupe. Referring to the graph (fig. 6-B), it will be seen that most of the isolations are extremely virulent. However, a few isolations worked very slowly, and one very weak isolation never caused anything more than incipient though undoubtedly true bacterial wilt. It will be noted that most of the isolations (84 in number) fall above the virulence index 0.033, and it may be added that all the isolations from squash are within this group.

As a supplementary test, 62 of these isolations from cucumber, squash, and cantaloupe were further tested as to relative virulence when inoculated into White Bush Scallop squash, the method used being the same as in the cucumber tests above described. Reference to the graph (fig. 6-A) shows the opposite kind of a curve from that obtained with cucumber as indicator. Only 12 out of the 62 isolations tested caused wilting of entire squash plants, and a lower degree of relative virulence was shown here than when these same isolations were tested by inoculation into cucumber. Of these 12 highly virulent isolations it happens that 6 were originally obtained from cucumber and 6 from squash. Eighteen other isolations tested on squash exhibited various shades of virulence from incipient wilt only up to the wilting of one to several leaves, but never caused wilting of an entire plant. Of this group, 14 isolations were from cucumber, 2 from squash, and 2 from cantaloupe. The third and last group, made up of 23 isolations from cucumber, 2 from squash, and 7 from cantaloupe, falls upon virulence index zero—that is, none of these isolations gave any apparent infection at all on White Bush Scallop squash, although all had caused infection in cucumber. In cases of recovery of a squash plant after partial wilting, *Bacillus tracheiphilus* may continue to live in the vascular tissue of the apparently healthy plant. In one such instance plates were poured from the fruit of an inoculated squash plant about one month after apparently complete recovery from wilt,

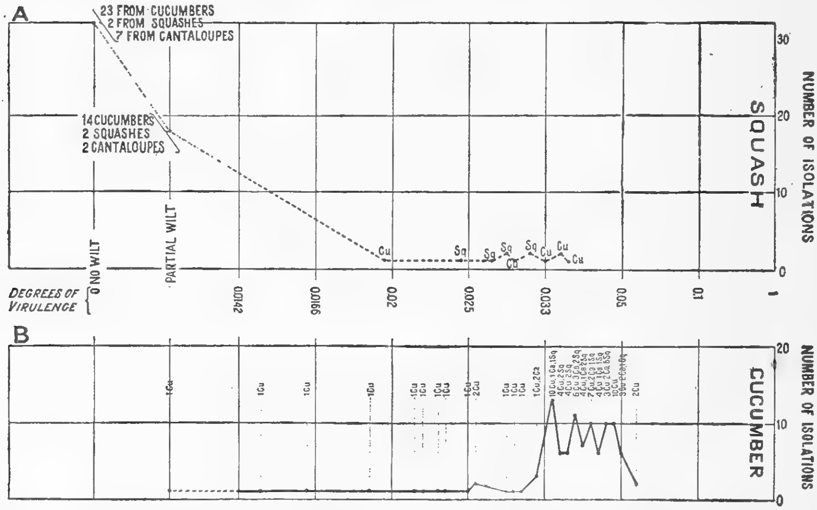

FIG. 6.—Curves showing the varying degrees of virulence among different isolations of *Bacillus tracheiphilus* from the three common hosts and from many sections of the country as demonstrated by large numbers of inoculations into squashes (*A*) and into cucumbers (*B*), 62 different isolations being tested in this way on squashes and 103 on cucumbers. The letters *Cu*, *Ca*, and *Sq* refer to the source of the isolation as being cucumber, cantaloupe, or squash, and the figures preceding refer to the total number of isolations from each host possessing a similar degree of virulence.

and *B. tracheiphilus* was recovered from these plates and proved infectious by inoculation into cucumber.

A large proportion of all the isolations were retested on both cucumber and squash in April, 1918, and essentially the same relations have continued to hold after long periods. For example, two isolations (*R 230*, New York; *R 235*, Michigan) from cucumber carried continuously in culture since August, 1914, and tested from time to time by inoculations, have preserved approximately the same virulence to Chicago Pickling cucumber and the same relation to each other during all this time, *R 230* being considerably more virulent than *R 235*.

Furthermore, in 1915 these two isolations were inoculated into cucumber plants and then reisolated. The reisolations (*En 14* from *R 230* and *En 15* from *R 235*) were found still to retain approximately the same virulence relations as the originals. The relative virulence indexes of these four isolations as deduced from many series of cucumber inoculations are, respectively, 0.0384 and 0.0366 for *R 230* and *En 14* and 0.0218 and 0.0229 for *R 235* and *En 15*.

The least virulent isolation (*En 160* B) of the series which at any time caused complete wilting in cucumbers had a relative virulence index of 0.0149. This was one of four isolations made from slightly wilted cucumber vines collected at Goldsboro, N. C., in June, 1916. One of these cucumber isolations (*R 317*) made in the field caused wilting of only a few cucumber leaves, never of entire plants. The other three isolations (*En 160* A, B, C) were from cucumber material collected in this same locality and sent to the laboratory at Washington, D. C., for isolation. These three isolations sometimes caused wilting of entire plants after a comparatively long time and in other cases caused only partial wilting. The bacterial wilt was rare in the vicinity of Goldsboro, and only after careful search were these few cases found. With the exception of this Goldsboro locality all the southern isolations possessed a comparatively high degree of virulence.

Leaving out the one very exceptional case at Goldsboro, N. C., the average indexes of relative virulence for all cucumber isolations grouped according to geographical source were as follows: Ten isolations from Norfolk, Va., southward, 0.042; 15 from the District of Columbia, 0.041; 17 from Long Island, 0.040; 7 from middle New York to Canada, 0.036; and 9 from Michigan, Wisconsin, and northern Iowa, 0.032. As will be readily noticed, the average virulence is highest in the South and gradually decreases northward. A study of the figures making up these averages shows that the southern isolations as a whole tended to higher virulence, while the northern isolations contained examples of both high and low virulence instead of decreasing as a unit. The higher virulence of the southern isolations is shown also by the fact that out of seven isolations from cucumbers obtained in North Carolina, South Carolina, Georgia, and Alabama, six of them (*R 318, 320, 321, 323, 324,* and *325*) were found capable of causing wilt in White Bush Scallop squash. Of the northern isolations from cucumber, the larger number obtained have caused no apparent infection when inoculated into squash.

The isolations from squash and cantaloupe when grouped according to geographical source have shown this same general tendency, but not in quite so marked a degree, since all isolations from these hosts have fallen within the more highly virulent group.

Viewing the general results of these relative virulence tests, it seems possible that instead of having only two distinct and well-differentiated biological strains of *Bacillus tracheiphilus* we may be dealing with a long series of "races" or "pure lines" of the organism exhibiting among themselves closely intergrading degrees of virulence for their various hosts. Wilt goes from cucumber to squash as well as from squash to cucumber. Furthermore, although among cucumber isolations the larger percentage are extremely virulent when inoculated into cucumber, while the larger percentage do not cause any signs of the disease at all in squash, the considerable number of cucumber isolations remaining which do cause appreciable infection in squash exhibit all grades of host reaction—the minutest signs alone, wilt of only a few square millimeters around the inoculation points, wilt of a considerable portion of the inoculated leaf, wilt of one to several leaves, and finally, in the case of the more virulent isolations, wilt of the entire squash plant.

However, the factors causing resistance or susceptibility to the wilt disease in cucumbers may be more or less distinct from the factors causing resistance or susceptibility in squash. Thus, there may still be a distinct cucumber strain represented by those of our isolations which never caused infection in squash and a squash strain possessing not only the factors necessary for infection in cucumber but additional factors enabling it to attack squash also. If this is the case, in all probability some means will be found of distinguishing the two strains by morphological or cultural characters of the parasite. Thus far, however, no constant morphological or cultural differences have been found between cucumber and squash isolations or between isolations of greater or less relative virulence. The only constant differences as yet noted among the various isolations have been differences in relative virulence to a given host. The fullest tests have been made upon Chicago Pickling cucumber, but smaller tests have also been carried out upon Arlington White Spine cucumber and upon White Bush Scallop and Yellow Crookneck squashes. While in these tests the individual isolations have not preserved exactly the same order of relative virulence when inoculated into the different host species and varieties, the tendency has been in this direction. That is, isolations most or least virulent to Chicago Pickling cucumber tended to be, respectively, most or least virulent to Arlington White Spine cucumber; and many though by no means all isolations highly virulent to cucumbers have been found capable of infecting squashes to a greater or less degree, while isolations of low virulence to cucumbers have invariably given no infection at all on squashes. This last group Dr. Smith called *Bacillus tracheiphilus* forma *cucumis*. Apparently the factors in the parasite causing high virulence to cucumbers are necessary to infection in squashes, for none of the isolations weak in virulence to cucumbers has caused any infection at all in squashes. But not all of the isolations highly virulent to cucumbers will cause infection in squashes. Thus additional qualities in the parasite may be necessary for squash infection, and it is entirely possible that besides the many races or pure lines of the organism showing various degrees of relative virulence to any particular host there may be also distinct cucumber and squash strains.

SOME HOST RELATIONS.

On the other side of the host-parasite relation the species and varieties of cucurbits themselves differ in susceptibility to the wilt organism as a whole and to its various races. Thus cucumbers constitute the most susceptible host species so far tested, and most of the isolations have proved highly virulent to them. Some differences in varietal susceptibility have been observed, but none have shown marked resistance, and apparently little hope of control through resistant varieties is given here.

At the other extreme are watermelons, the most resistant of our economic cucurbits. No authentic report of natural infection to this host has come to our notice, and our inoculations have given negative results or at most a very slight local wilt immediately around the points of inoculation.

The squash group stands next to the watermelon in resistance. Unlike the cucumber, most isolations tested on squash have given no infection or only slight local wilting. The few remaining were highly virulent, but slower in developing the disease than when inoculated into cucumber. Much greater differences in varietal resistance were shown within the squash group than among cucumbers.

Aside from the differences in resistance inherent in the species and varieties of cucurbits, a further cause of variability in the host reaction to the parasite appears to be directly connected in some way with the growth condition of the host at the time of inoculation.

It has long been thought by many growers that the spread of wilt and the extent of damage done are in some way connected with weather conditions. In two different papers, W. G. Sackett [1] states that growers seem to think that wilt is worse during wet weather and just after a heavy rain, especially if the sun comes out hot. He says further that if this is true it is probably due to the fact that these conditions favor growth of the germs and bring about a more rapid distribution of the bacteria through the plant.

G. H. Coons [2] thought it probable that hot, dry summers, such as the summer of 1911, might do much to check the spread of the disease by drying out the wounds made by insects before the bacteria could obtain a foothold. He stated further that perhaps the temperature conditions alone are sufficient to check the growth of the disease.

[1] Sackett, W. G. Some bacterial diseases of plants prevalent in Michigan. Mich. Agr. Exp. Sta. Bull. 230, p. 217, 1905.

——— Some bacterial diseases of plants. Colo. Agr. Exp. Sta. Bul. 138, p. 22–23, 1909.

[2] Coons, G. H. Cucumber and muskmelon wilt. *In* Mich. Farmer, v. 140, no. 1, p. 1–2, illus. 1913.

Reviewing our own work and observations, these assumptions apparently have considerable truth in them, but they do not appear to express the whole truth. Among the enormous number of inoculations made during the past four seasons, several common factors have been observed running through them all. In our greenhouse experiments during the winter months very little or no difference in the percentage of infection or the rate of progress of the disease has been observed between plants sprayed with tap water immediately preceding inoculation and other plants of the same age and vigor inoculated when dry. The same infection relations also have held between greenhouse inoculations made in sunlight and those made on cloudy days or under shade.

On the other hand, striking differences are often shown among plants in varying states of vigor or age. After inoculation, badly stunted or old plants have in general shown a very much lower percentage of infection and slower progress of the disease than young vigorously growing plants of the same variety. These facts have repeatedly been observed during the progress of our studies, and for this reason great care has been exercised in selecting plants for virulence tests.

From these observations, together with the beetle and wilt curves and the meteorological data obtained in field experiments (figs. 2 to 4), it appears that within rather wide limits weather conditions have very little direct effect on the percentage of infection. However, a rapid, sappy growth of the vines favors infection and spread of the disease through the plant; whereas senility in the host, whether due to normal maturity or to unfavorable conditions such as drought or lack of plant food, furnishes conditions unfavorable to infection and spread of the bacteria within the plant. Thus, by inducing rapid succulent growth of the vines rainy weather may indirectly raise the percentage of infection and increase the reproduction of the bacteria inside of the plant. If, then, following such a rainy period the sun suddenly comes out hot, any tendency to wilt will obviously become evident at once. Indeed, under these circumstances, the excessive transpiration from too rapidly growing tissues often causes transitory wilting where no parasitic organisms are present. On the other hand, after a long period of drought the prevalence of wilt often decreases, not directly because of the weather conditions but because the vines have hardened up and no longer favor infection. Furthermore, periods of drought often come at midseason when senility is normally approaching, and the weather conditions serve only to hasten and intensify the natural process of ripening. A decrease in number of cucumber beetles between broods often comes simultaneously with these midseason drought conditions and this again reduces the number of infections at their source. Undoubtedly an extremely dry atmosphere coupled with prolonged temperatures at or above the maximum for growth of the wilt bacteria will reduce the percentage of infection and rate of progress of the disease, and in extreme cases the wilt may be even practically stamped out. However, under ordinary field conditions in the Northern and Middle States, the limiting factors appear to be (*a*) the presence of wilt-carrying beetles and (*b*) a vigorous, succulent growth condition in the host.

Certain data relative to the incubation period of the wilt organism have been compiled from our inoculation experiments and field records. Among 295 sets of greenhouse inoculations on cucumber seedlings, in each case using two or more plants 6 to 18 inches high, the great majority showed signs of wilt in 4 to 6 days after needle-prick inoculation, wilting of the first leaf in 5 to 8 days, and complete wilting of

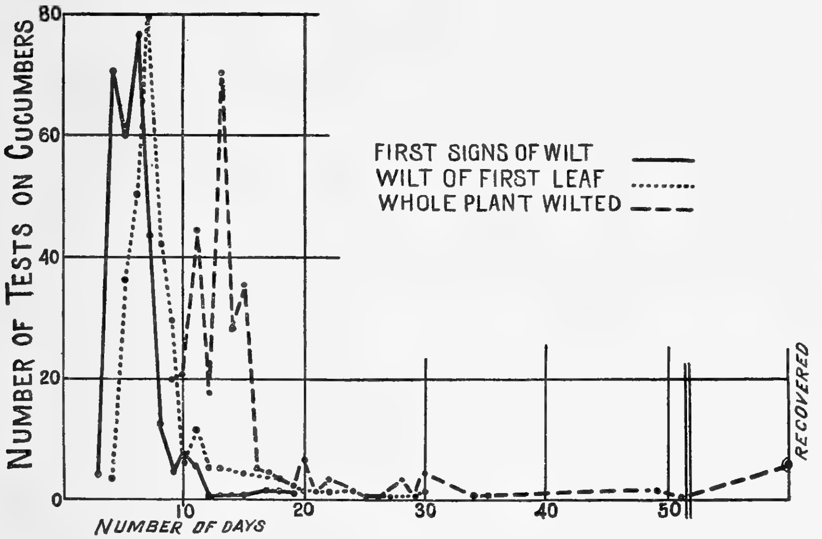

FIG. 7.—Diagram showing the progress of wilt in 295 inoculation tests on cucumbers (mostly the Arlington White Spine variety), with two or more plants in each test and in all using 103 different isolations of *Bacillus tracheiphilus*.

the plant in 11 to 15 days (fig. 7). Comparatively few of these cucumber plants took more than three weeks for complete wilting, and out of the whole 295 experiments only 6 exhibited any cases of recovery after once showing signs of the disease. Upon reference to the notes it was found that our 5 least virulent isolations (*En 15*, *R 235*, *R 311–a*, *R 317*, and *En 160*) had been used for inoculation in these 6 experiments. These 5 isolations were all low in virulence, but, with the exception of *R 317*, they usually caused complete wilting of a plant in the end.

In 51 inoculation tests on squash seedlings 6 to 12 inches high most of the plants showed incipient wilt in 5 to 8 days, wilting of the first leaf in 6 to 13 days, and complete wilting, where it occurred at all, in 15 to 20 days after inoculation (fig. 8). However, in 26 out of the 51 sets of inoculations the plants all recovered after partial wilting. It will be noted that the first signs of the disease and wilting of the first leaf were only a little slower in appearing than in cucumber, but in general a much longer time elapsed before the whole plant became involved. A far greater percentage of recovery was exhibited than in cucumber.

Field records during 1916 in the spray plat at East Marion, Long Island (fig. 1, Field IIa), showed that among the cucumbers where wilting of the first leaves appeared on July 12 the larger number of plants had completely succumbed six days later (July 18). The vines at this time were 1 to 2 feet in length, which was approximately the size of those used in the greenhouse inoculation tests above noted, and it will be seen at once that the period between the wilting of the first leaves and the total wilting of the plant corresponds very closely under the field conditions and the greenhouse conditions.

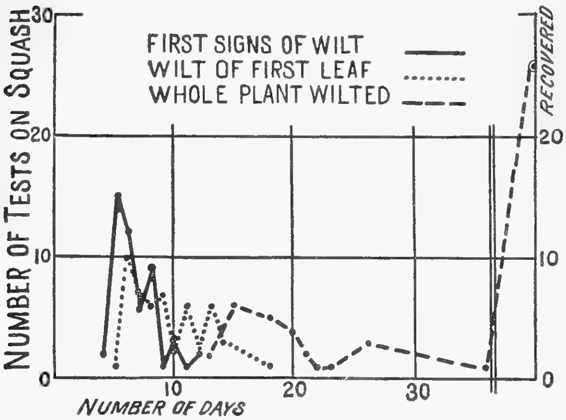

FIG. 8.—Diagram showing the progress of wilt in 51 inoculation tests on squash (mostly the White Bush Scallop variety), with two or more plants to a test and in all using 21 different isolations of *Bacillus tracheiphilus*.

Of the plants which showed wilting of the first leaves on July 18 the larger number had completely wilted 11 days later, while of those with first wilt on July 29 the larger number lived for 17 days longer. Complete records of later infections could not be obtained, on account of the appearance of downy mildew.

As would be expected, the larger the plant the longer the period of time elapsing between initial and total wilting. However, the two are not directly proportional, since in the older plants the absolute progress of the disease is slowed down through some relation to the condition of senility in the host. (Cf. pp. 31 and 32.)

DISTRIBUTION OF BACTERIAL WILT.

Bacterial wilt of cucurbits was reported by Dr. Erwin F. Smith[1] as occurring (fig. 9) in Canada, Massachusetts, Vermont (?), Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, District of Columbia, Virginia, West Virginia, Pennsylvania, Ken-

[1] Op. cit., p. 209–211.

tucky, Ohio, Indiana, Illinois, Michigan, Wisconsin, Missouri, Iowa, Nebraska, and Colorado, and as having been reported also from Germany, Russia, and the Transvaal. He states that "nothing is known of its occurrence south of Virginia." On account of the low thermal death point of the organism and the lack of reports or specimens of the disease from the States south of Virginia he was rather of the opinion that it would not be found to occur in the far South, except in the more mountainous parts.

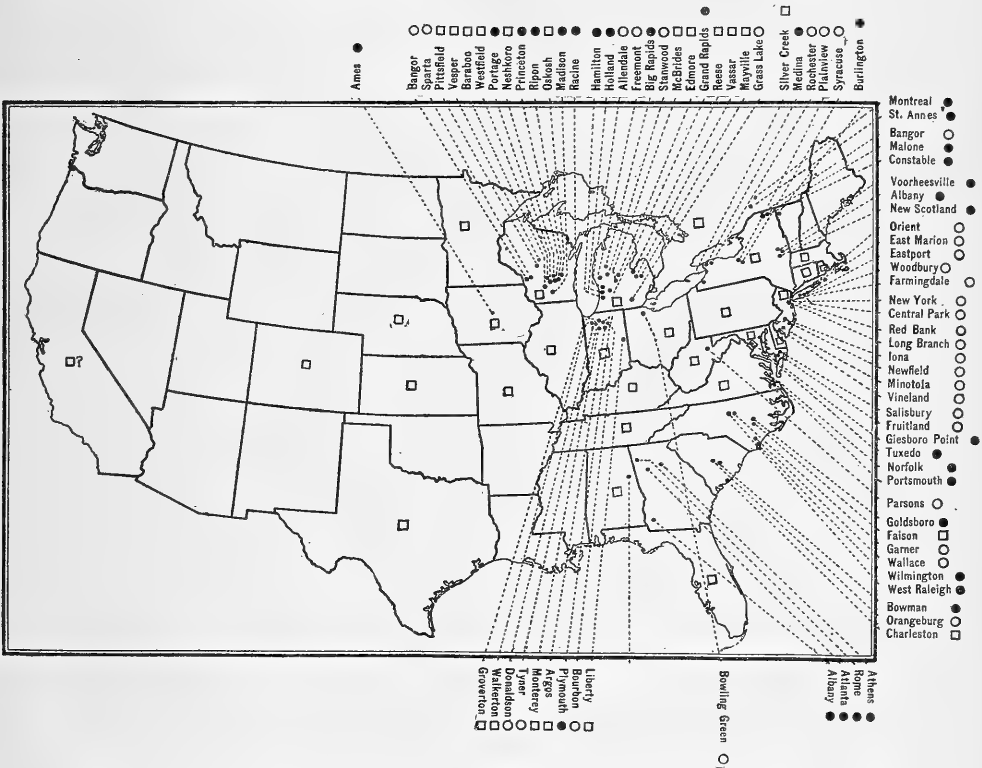

FIG. 9.—Map of the United States, showing the distribution of the bacterial wilt of cucurbits. ○=Bacterial wilt seen by one or both of the writers. ●=Isolations of *Bacillus tracheiphilus* made by one or both of the writers. □=Bacterial wilt reported by other pathologists, either with or without specific locality.

In 1914, F. M. Rolfs [1] reported this disease as causing serious losses to cucumbers in the vicinity of Charleston and Beaufort, S. C. With this exception no published reports of its occurrence south of Virginia and east of the Mississippi River had been found, and letters to experiment station pathologists from North Carolina to Louisiana had given no other definite information.

Accordingly, during June and July, 1916, a scouting trip was made by the senior writer through North Carolina and South Carolina,

[1] Barre, H. W. Report of the botanist and plant pathologist. S. C. Agr. Exp. Sta., 27th Ann. Rpt., [1913]/14, p. 23. [1915.]

Georgia, and parts of Alabama for the purpose of obtaining further information as to the southern distribution of bacterial wilt of cucurbits. The disease was found and pure cultures of *Bacillus tracheiphilus* were obtained from all four States above named. Later inoculations with these cultures into cucumbers in the greenhouse at Washington, D. C., gave typical wilt infection in every case, thus fully establishing the presence of the disease in these four Southern States. Specifically, natural infection was found on cucurbits in the field at West Raleigh (cucumber isolation *R 316–a*), Wilmington (cucumber isolation *R 318*), Goldsboro (cucumber isolations *R 317* and *En 160* and cantaloupe isolation *En 161*), and Garner, N. C.; at Orangeburg and Bowman (cantaloupe isolation *R 319*), S. C.; at Albany (cucumber isolation *R 320*), at Athens (cucumber isolation *R 325*), Atlanta (cucumber isolation *R 323*), and Rome (cucumber isolation *R 322*), Ga.; and at Anniston (cucumber isolation *R 321*), Ala. The southernmost location visited was Albany, Ga., and here bacterial wilt was found on both cucumbers and cantaloupes. The worst damage in any of these cases occurred at Anniston, Ala., and Rome, Ga., where in some cases as high as 25 per cent of the cucumber or cantaloupe vines had succumbed. In the far southern or coastal localities wilt was doing very much less damage, but this may have been partly due to the lateness of the cucumber season at the time the observations were made. In some of these localities (e. g., Charleston, S. C.), the cucumber season was entirely past, so that nothing but ripe fruit and dead vines were left.

Reference to the map (fig. 6) will show all the localities in which we have found this disease and from which we have obtained cultures, as well as the States from which the disease has been reported by other pathologists. Most of the reports of "specific localities" by other pathologists are from unpublished notes of Mr. W. W. Gilbert, of the Bureau of Plant Industry. During 1917 and 1918 bacterial wilt of cucurbits was reported by the Plant-Disease Survey [1] not only from portions of the United States where it had hitherto been known to occur, but also from Alabama, Florida, Tennessee (Essary), Texas (J. J. T.), Kansas (Melchers), and probably also from California. The disease was also reported as never having been seen in the State of Maine.

CONTROL.

Relative to the problem of control, at least four courses lie open—(1) the finding or developing of resistant varieties, (2) spraying the plants with a bactericide, (3) eliminating the beetles through poisons or repellents, and (4) removing wilted plants as sources of spread through the beetles.

[1] U. S. Department of Agriculture, Bureau of Plant Industry, Plant-Disease Survey, Plant-Disease Bulletin, v. 1, no. 5, p. 92; no. 6, p. 101, 1917; v. 2, no. 4, p. 58; no. 10, p. 181, 1918.

VARIETY TESTS.

The results of the tests already published [1] give little hope of control in cucumbers or cantaloupes through resistant varieties. A second variety test on Long Island (1916) and a third at Tuxedo, Md., (1917) have not changed this conclusion. Wilt infection is rarely as bad in squashes as in cucumbers or cantaloupes and it is not often serious enough to require special control measures. The variety tests showed greater differences in resistance among squashes, and should control become necessary it is possible that fairly immune varieties might be developed.

SPRAY TESTS.

The earlier spray tests [2] were repeated (1916) at East Marion, Long Island, on a larger scale and with some modifications. On May 12,

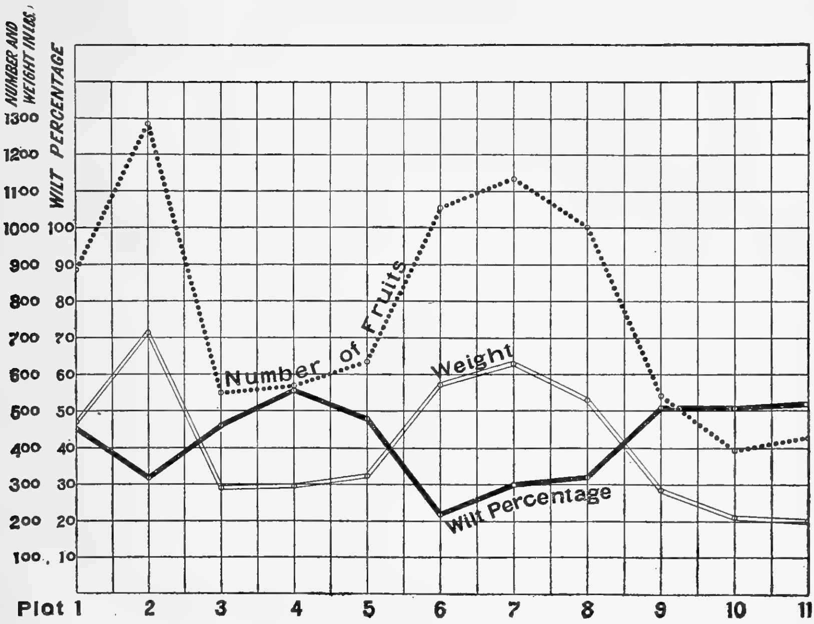

FIG. 10.—Curves showing the percentage of bacterial wilt and the weight and number of fruits in 11 plats of the cucumber spray test, East Marion, Long Island, N. Y., season of 1916.

1916, Woodruff's Hybrid cucumbers were planted in hills 3 by 4 feet apart on a level and uniform strip of land about one-half acre in extent. This area was divided into 11 plats, each containing 81 hills. Two of these plats were left untreated as controls, and one plat was treated to equal parts of lime and tobacco dust, while the remaining 8 plats were given spray applications varying as to number and ingredients. The dates of application of the various treat-

[1] Rand, F. V., and Enlows, Ella M. A., 1916. Op. cit., p. 426–428.

[2] Rand, F. V., and Enlows, Ella M. A., 1916. Op. cit., p. 429–433.

ments were June 19, 28, July 6, 13, 18, 28, August 3, 13, and 16. Table I gives the details as to the number of plants, kind and number of treatments, and wilt records for each plat in the field, and figure 10 shows graphically the relative effect of the various treatments as compared with the control plats. Photographs of plats Nos. 1, 6, and 11, taken August 25, 1916 (Pls. II and IV), show the appearance of the vines with all the applications of Bordeaux mixture and lead arsenate, with lead arsenate alone, and also without any treatment. Each stake shown in these photographs represents one case of wilt. In all cases the cucumbers were picked when about 6 inches in length. No new or special combinations of insecticides were used in this test, as the insect control, per se, is a matter left to the Bureau of Entomology. In the earlier tests, Bordeaux mixture with lead arsenate gave a better control than either mixture alone, so that 2 pounds of lead arsenate paste were added to each 50 gallons of Bordeaux mixture used in this experiment.

TABLE I.—*Bacterial wilt record of the spray experiment in Field IIa at East Marion, Long Island, 1916.*

Treatment.	Plat No.	New cases of wilt at different dates.						Number of plants at the start.	Wilt for the season.	
		July—			August—				Total.	Percentage.
		11	18	29	9	15	23			
Control, unsprayed	1	6	12	56	25	11	1	248	111	45
Bordeaux mixture plus lead arsenate:										
1-2-50-2, all applications	2	7	7	50	29	6	4	325	103	32
2-3-50-2, first two only	3	8	21	48	12	14	3	230	106	46
2-3-50-2, first only	4	3	26	52	43	5	2	234	131	56
2-3-50-2, all but first four	5	3	8	58	33	6	2	227	110	48
2-3-50-2, all applications	6	1	6	21	17	7	8	267	60	22
2-3-50-2, all but first	7	3	5	30	24	15	5	268	82	30
2-3-50-2, all but first and second	8	9	12	36	20	4	9	282	90	32
Control, unsprayed	9	2	32	41	26	14	3	231	118	51
Lime and tobacco dust, all applications	10	7	48	51	18	8	2	260	134	51
Lead arsenate, 2-50, all applications	11	11	19	66	16	18	7	264	137	52
Total	......	60	196	509	263	108	46	2,836	1,182	......

It will be noted that the reduction of wilt was greater with the 2–3–50 Bordeaux mixture than with the 1–2–50 mixture, although the number and weight of fruit picked was slightly greater for the weaker mixture. The wilt records show the effect of the treatments on the wilt alone, while a comparison of the number and weight of fruit for the various plats shows the combined control against both wilt and downy mildew (caused by *Pseudoperonospora cubensis*). The latter disease became prevalent during the month of August (fig. 3). For control of wilt the last five treatments had no appreciable effect. Of the remaining four applications the two most effective were made July 6 and 13, respectively, and it thus seems apparent that the greater portion of wilt infections took place during the first half of July. Reference to the beetle and wilt curves for this field (fig. 3) shows that this was during the period when the striped cucumber beetles were becoming less prevalent; but when it is known that wilt usually appears within less than two weeks after inoculation it is seen that this period of greatest probable infection corresponds with the curves showing the actual appearance of wilt (fig. 3, II and IIa) in these two contiguous spray and cage-test blocks.

During the following season (1917) another spray test was carried out near Tuxedo, Md., using Arlington White Spine cucumbers. The purpose of this experiment was to compare different strengths of Bordeaux mixture, as well as to gain further general evidence along the line of control. Applications of each mixture were made on June 13, 18, 25, July 2, 9, 17, 23, 30, and August 6, making nine treatments in all. Reference to Table II will show the different mixtures used and the numbers and percentages of wilted plants in the different plats. Two pounds of lead arsenate paste were added to each 50 gallons of Bordeaux mixture used. The total number of plants in each plat is based on the assumption of three to a hill, since they were thinned to approximately this number early in the season. Wilt in this field was not quite as serious as in the Long Island locality.

TABLE II.—*Spray experiment at Tuxedo, Md.*

Plat No.	Treatment.	Number of plants at the start.	Number of cases of wilt.	Percentage of wilted plants.
I	Bordeaux mixture plus lead arsenate, 2–3–50–2	225	37	16.4
II	Control, unsprayed	225	94	41.7
III	Bordeaux mixture plus lead arsenate, 3–4–50–2	225	35	15.5
IV	Bordeaux mixture plus lead arsenate, 4–5–50–2	225	26	11.5
V	Control, unsprayed	225	80	35.5
VI	Bordeaux mixture plus lead arsenate, 4–2–50–2	177	5	2.8
VII	Control, unsprayed	99	30	30.3

The percentage of cases in the three unsprayed plats varied from 30 to 42 per cent, while in the four sprayed plats only 3 to 16 per cent of the plants wilted. The fungicide was progressively more effective as the amount of copper sulphate was increased, the 4–2–50 formula reducing the wilt to about 3 per cent. However, the excess of copper sulphate in this last mixture seriously burned the foliage, so that its general use can not be recommended. The 4–5–50 Bordeaux mixture with 2 pounds of lead arsenate paste gives the best control of any treatment we have thus far used in our experiments.

PULLING TESTS.

Since the cucumber beetles originally become carriers through feeding on wilt-infected plants, it was thought possible that by pulling the wilted plants during the early part of the season an appreciable measure of control might be effected. Accordingly at East Marion, Long Island (May 24, 1916), 200 hills of Woodruff's Hybrid cucumber were planted in an isolated block, the location of which is shown in figure 1, Field IV. There were 800 plants in the field after thinning and at the time the first wilt appeared (June 29). Wilted plants were pulled and removed from the field 10 times through the season, on the following dates: June 29, July 11, 13, 18, 21, 27, 31, and August 11, 18, and 25. During the course of the season 249 plants wilted, or 31 per cent of the total number left after thinning. In the control, untreated plats of spray-test Field IIa in this same locality (fig. 1) the amount of the disease varied from 45 to 56 per cent, while of about 1,000 unsprayed plants in Field II (fig. 1) 60 per cent wilted. Thus the control by pulling of wilted plants was entirely as effective as that by the weaker Bordeaux mixture used.

This experiment was repeated in 1917, near Tuxedo, Md., using Arlington White Spine cucumbers. The number of plants left after thinning was 1,046, while 332, or a little less than 32 per cent, contracted wilt and were pulled during the season. The average wilt in the three untreated plats of the neighboring spray test was about 36 per cent. Thus a slight difference is to be noted in favor of pulling the wilted plants, but the result is by no means so well marked as in the Long Island test. However, the Tuxedo plat was located in a field of cucurbits and was separated from other cucumbers and cantaloupes only by a strip of watermelons 3 rods wide, while the test plat on Long Island was about one-eighth of a mile from any other cucurbits, and corn and other noncucurbitaceous crops occupied the intervening area.

Clearly some measure of control is effected by the pulling of wilted plants, but the presence of a neighboring field where this control method is not practiced may largely nullify the good results.

CONTROL IN GREENHOUSES.

The senior writer has in some cases found serious damage from wilt on cucumbers in commercial greenhouses. In these instances the striped cucumber beetle has clearly been the first source of infection, though the greenhouse workers have sometimes continued the spread of the disease with much greater efficiency than the original carrier. Cases have been noted where wilt infection has followed down the row on one side of a greenhouse bed, taking nearly every plant, while on the other side of the same bed scarcely a single case could be found. Here the evidence is clear that pruning instruments were the carriers of infection.

SUMMARY.

As a result of our studies on bacterial wilt of cucurbits during the period 1914–1918, considerable new information regarding the disease and its relations to insects has been obtained.

The disease occurs in 31 States, including the territory from Vermont and Canada to Florida and west to Minnesota, Nebraska, Colorado, and Texas. It also probably occurs in parts of California. Of our common domestic cucurbits the disease affects cucumbers, cantaloupes, summer and winter squashes, and pumpkins, but not watermelons.

The severity of the disease varies widely in different seasons and localities from an occasional wilted plant up to a destruction of 75 to 95 per cent of the crop. There is very little direct relation between percentage of infections and severity of the disease and ordinary weather conditions in the North, but there is a direct relation to prevalence of cucumber beetles and condition of vigor in the host plant.

Careful and extensive experiments have shown that infection does not come through soil or seed; that the squash bug (*Anasa tristis*), squash lady bird (*Epilachna borealis*), melon aphis (*Aphis gossypii*), potato flea-beetle (*Epitrix cucumeris*), and honeybee (*Apis mellifera*) are not wilt carriers; but that the striped cucumber beetle (*Diabrotica vittata*) and the 12-spotted cucumber beetle (*D. duodecimpunctata*) are both summer carriers and probably the only means of summer transmission of the disease in the localities studied. Infection through the breathing pores of the plant does not occur, introduction of virulent bacteria into the interior plant tissues being necessary for infection.

It has been definitely proved that bacterial wilt of cucurbits does not winter over in the soil, and all seed tests have given negative results. The disease has been carried experimentally for six weeks by striped cucumber beetles hibernated artificially in cold storage. We have thus far been unable to hibernate the beetles for a longer period.

Considerable circumstantial evidence, however, points to cucumber beetles as winter carriers. For example, among the first collections of beetles in the spring a small percentage were found to be wilt carriers. The earliest cucurbits were still very small and no wilt was anywhere in evidence. Futhermore, a careful record of spring sequence of wilt was kept in all field and garden plats of cucurbits in two localities and in all cases the leaves first showing wilt in the spring had typical cucumber-beetle injuries; the wilt had plainly started from these injured points, and there was a tendency for wilt to spread in groups around the original cases, in each new plant starting from beetle-injured leaves. In many of the cases such beetle injuries had not become general at this time throughout the fields.

After one initial feeding, striped cucumber beetles are sometimes capable of infecting at least four healthy cucumber plants successively fed upon, and after one wilt feeding some individuals in the active condition have still been capable of giving infection as long as 23 days afterwards.

Dissection and inoculation experiments have shown virulent wilt bacteria present in the intestines of a portion of the beetles fed on wilted plants, and isolations of intestinal bacteria so far as tried showed in most cases an acid-forming and gas-forming flora antagonistic to the wilt organism; but in 10 per cent (one experiment only) of the beetles used the intestinal bacteria were not inimical to the wilt organism, the latter remaining alive and causing infection in cucumber plants after three weeks' growth in mixed culture with the intestinal bacteria.

In the extensive virulence tests the various isolations of *Bacillus tracheiphilus* from different hosts and localities have shown wide and fairly constant differences in relative virulence to a given host variety. While in these tests the individual isolations have not preserved exactly the same order of relative virulence when inoculated into the different host species and varieties, the tendency has been in that direction. That is, isolations highly or weakly virulent to one variety of cucumbers have tended, respectively, to be highly or weakly virulent to another variety, and many though not all isolations highly virulent to cucumbers have been found capable of infecting squashes to a greater or less degree, while isolations of low virulence to cucumbers have invariably given no infection at all in squashes. It is entirely possible that in addition to the many races of the parasite exhibiting varying degrees of relative virulence to any particular host species there may be also two distinct strains for cucumber and squash.

Cucumbers are the most susceptible host species thus far tested and watermelons the most resistant of any species which has shown any host reaction at all. No authentic report of natural infection on watermelon has been found, and inoculations have given either negative results or at most a very slight local wilting. Cantaloupes are slightly more resistant than cucumbers, while the squash group stands next to watermelons in order of resistance.

In greenhouse tests, given similar plants to start with, very little difference in the percentage of infection or progress of the disease occurs between wet versus dry inoculations or between those made in sunlight versus shade. On the other hand, badly stunted or old plants have in general shown a much lower percentage of infection and slower progress of wilt than young, vigorously growing plants of the same variety. Ordinary variations in weather conditions have very little direct effect on percentage of infection, but may possibly have some effect on the rate of wilting. The principal essentials to maximum damage in cucumbers from wilt disease in the Northern and Middle States consist in maximum numbers of wilt-carrying cucumber beetles together with succulent, rapidly growing vines. Given these conditions, the injury will be severe with either wet or dry weather and within a considerable range of temperature.

Where the disease is likely to be severe, spraying with strong Bordeaux mixture and lead arsenate powder (4–5–50–2) is recommended. Treatments should begin as soon as the cucumber plants develop their first true leaves and should continue at intervals of about a week until the cucumber beetles practically disappear from the field. In localities where downy mildew is also prevalent the treatments should be continued later as a partial insurance against this disease. The beetles prefer unsprayed plants as food, and undoubtedly the efficiency of wilt control would be enhanced if a slightly earlier trap crop, such as squash, were planted along the edges of the cucumber field. The beetles could be poisoned there with a strong insecticide.[1]

The pulling of wilted vines during the first part of the season, or as long as it can be done without mechanically injuring the healthy plants, will greatly assist in controlling bacterial wilt if consistently done in all neighboring fields. The diseased vines should be buried or otherwise removed from access by the beetles.

Where a few plants only are grown in garden plats, screening the hills with fine mosquito netting will prevent the appearance of the disease. On a large scale this method of control obviously would be impractical.

For control in greenhouses the beetles should be kept out in the first place if possible. Do not grow cucurbits nor pile cucurbit refuse in the immediate vicinity of greenhouses, as this attracts the beetles and many will later find their way into the houses. If the beetles once gain entrance to a house filled with growing plants hand picking is the only remedy to be recommended until some fumigant is found that will kill the beetles without injuring the cucumber plants. Besides destroying the cucumber beetles, great care must be exercised in disinfecting all instruments used in pruning wilted vines before using them again on healthy plants. This may easily be done with a bottle of 1 to 1,000 mercuric chlorid and a sponge. In some cases it may be advantageous to keep the beetles out by screening doors, ventilators, and other openings into the greenhouse. For this purpose a netting with 18 meshes to the inch will be necessary.

[1] Directions for the control of the striped cucumber beetle are given in Farmers' Bulletin 1038. (Chittenden, F. H. The striped cucumber beetle and its control. U. S. Dept. Agr. Farmers' Bul. 1038, 20 p., 15 figs. 1919.) This publication may be obtained free on application to the Secretary of Agriculture, Washington, D. C. The most approved methods as given include covering young plants, planting an excess of seed, clean culture, the use of trap plants, spraying with arsenate of lead and other arsenicals with or without Bordeaux mixture or the dry dusts, stimulation of growth, keeping the plants in good condition, and cooperation with neighboring growers of cucurbits in the use of control methods.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 829

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WM. A. TAYLOR, Chief

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THE MOSAIC DISEASE OF SUGAR CANE AND OTHER GRASSES.

By E. W. Brandes,

Pathologist, Sugar-Plant Investigations; formerly Pathologist, Porto Rico Agricultural Experiment Station, Mayaguez, P. R.

CONTENTS.

HISTORY OF THE DISEASE.

The mosaic disease of sugar cane, the presence of which has recently been discovered in Louisiana and other Southern States, is the malady that in epidemic form has occasioned severe losses in parts of Porto Rico during the past four years. There it has been variously called matizado, "mottlings;" rayas amarillas, "yellow stripe;" morida de perro, "dog bite;" la enfermadad de Arecibo, "disease of Arecibo;" la enfermadad nueva, "new disease;" etc. The disease was first noticed in Porto Rico about the middle of 1916.

Starting from some point near Arecibo, on the north coast of Porto Rico, it spread rapidly over the cane fields to the west, down the west coast to the south coast, and up into the valleys and hills of the interior throughout these regions. Its progress eastward was slower, but at the present time more than three-fourths of the cane fields of the island are invaded.

During the last 12 months, methods of control have been put into operation which have undoubtedly aided in checking the spread of the disease into new territory. It has appeared sporadically at a few points in the eastern fourth of the island, but the planters, thoroughly aroused and alert, have not permitted it to spread there as it has in the west. It has become the practice to inspect the fields regularly and eradicate diseased individual plants as they appear, thus removing the source of infectious material. This method has been successful where only a small percentage of the plants are infected. In the west, where 75 to 100 per cent of the plants in commercial fields are diseased, this method naturally can not be recommended. The average reduction in output of sugar for 10 mills in the worst infected area has been nearly 40 per cent, notwithstanding an increased acreage in cane, while the average output for 10 mills in the disease-free area shows a slight gain for the same period. These figures are approximate, but they indicate clearly the gravity of the situation.

The disease is not new, but was recognized as an undesirable condition in sugar cane as early as 1890 in Java, where it is called gele strepenziekte, "yellow stripe."[1] Owing to the failure of Dutch investigators to secure infection by artificial inoculation, they did not regard the disease as infectious, but rather as frequently recurring bud variations. This view was undoubtedly due to the fact that it had for years been present, but unnoticed and unrecorded as a specific disease, so that during this long period unconscious selection had eliminated all but the more or less resistant but not immune varieties of cane. Thus, where the disease had become endemic it would be especially injurious only to varieties imported from countries where the disease did not exist. It would be difficult to carry on successful infection experiments where the disease is as prevalent as it is in Java.

Dutch investigators reported the presence of yellow stripe in Egypt in 1909 on cane imported from Java and in the Hawaiian Islands in 1910. In the latter territory nearly all cane regions have become infested, and careful experiments have shown that where all plants in a field are attacked, according to Table I, it causes a reduction in yield of sugar of 5 to 40 per cent, depending upon the variety of cane.

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[1] Wilbrink, G., and Ledeboer, F. Bÿdrage tot de kennis der gele strepenziekte. Meded. Proefstat. Java-Suikerindus., No. 39, 2, p. 443–495, 5 pl. (4 col.), 1910.

TABLE I.—*Tests of sugar cane, showing varietal resistance to the yellow-stripe (mosaic) disease in the Hawaiian Islands.*[1]

Variety.[2]	Condition.	Canes.		Test of juice.			Requirement per ton of sugar.		Loss due to disease.
		Number.	Average weight.	Brix scale.	Sucrose.	Purity.	Weight of cane.	Number of canes.	
Plant cane (18 months old):			*Pounds.*	*Deg.*	*Per cent.*	*Per cent.*	*Tons.*		*Per cent.*
H 227	Striped	60	4.10	18.5	16.7	90.3	7.81	3,810	18.05
	Healthy	212	5.17	18.0	16.2	90.0	8.07	3,122	
H 151	Striped	50	5.73	18.4	16.5	89.7	7.95	2,775	15.20
	Healthy	248	6.57	18.8	16.9	89.9	7.73	2,353	
H 135	Striped	50	5.69	17.3	15.7	90.8	8.29	2,914	15.97
	Healthy	292	6.96	17.2	15.4	89.5	8.52	2,448	
H 90	Striped	57	5.50	18.5	16.6	89.7	7.90	2,873	20.64
	Healthy	244	7.08	18.3	16.3	89.1	8.07	2,280	
H 69	Striped	38	4.50	18.7	16.6	88.8	7.92	3,520	26.09
	Healthy	265	6.12	18.8	16.6	88.0	7.96	2,606	
H 38	Striped	16	5.12	19.3	17.7	91.7	7.33	2,863	5.83
	Healthy	296	5.60	18.8	17.2	91.5	7.55	2,696	
H 27	Striped	39	8.03	19.1	17.1	89.5	7.67	1,910	10.16
	Healthy	172	9.16	18.7	16.7	89.3	7.86	1,716	
H 2	Striped	16	4.00	18.8	16.9	89.9	7.73	3,865	34.9
	Healthy	174	6.39	18.5	16.4	88.6	8.04	2,517	
H 197	Striped	34	6.34	19.0	17.1	90.0	7.64	2,410	6.06
	Healthy	154	6.90	18.8	16.8	89.4	7.81	2,264	
H 276	Striped	32	6.01	18.1	15.7	86.7	8.49	2,825	14.46
	Healthy	196	6.96	18.2	15.8	86.8	8.41	2,417	
H 291	Striped	79	4.05	20.0	18.1	90.5	7.21	3,561	19.7
	Healthy	185	5.10	19.8	17.9	90.4	7.29	2,859	
H 338	Striped	20	4.00	19.8	17.6	88.8	7.47	3,735	46.45
	Healthy	191	5.50	20.2	18.0	89.1	7.31	2,659	
H 339	Striped	15	4.03	16.7	14.5	86.8	9.17	4,551	27.76
	Healthy	126	5.25	17.7	15.4	87.0	8.63	3,288	
H 355	Striped	219	5.25	18.8	15.5	82.4	8.81	3,356	13.72
	Healthy	70	6.03	19.2	15.7	81.8	8.73	2,895	
First ratooned cane (11 months old):									
H 363	Striped	75	4.73	19.3	17.2	89.1	7.65	3,235	8.04
	Healthy	66	5.13	19.2	17.2	89.6	7.63	2,975	
H 197	Striped	58	2.80	19.9	18.2	91.5	7.13	5,090	24.63
	Healthy	310	3.60	20.3	18.7	92.1	6.91	3,840	
H 109	Striped	109	3.99	19.5	17.9	91.8	7.22	3,619	.5
	Healthy	288	3.96	19.9	18.2	91.5	7.13	3,601	
H 69	Striped	84	3.50	19.0	16.7	87.9	7.91	4,520	14.76
	Healthy	213	4.08	19.1	16.8	88.0	7.86	3,853	
H 27	Striped	243	4.89	18.5	16.4	88.6	8.04	3,288	29.93
	Healthy	34	6.51	19.6	17.5	89.3	7.50	2,304	
Yellow Caledonia	Striped	16	2.56	19.7	17.8	90.4	7.33	5,727	26.1
	Healthy	372	3.66	19.1	17.0	89.0	7.74	4,229	
H 22	Striped	260	3.09	17.6	15.2	86.4	8.77	5,676	30.9
	Healthy	68	4.37	17.8	15.5	87.1	8.57	3,693	
H 20	Striped	24	4.10	19.3	17.3	89.6	7.08	3,454	11.97
	Healthy	345	4.73	19.9	18.1	91.0	7.19	3,040	

[1] Lyon, H. L. Losses due to yellow stripe disease. *In* Hawaiian Planters' Rec., v. 6, No. 5, p. 258–263, 1912. (Permission to use the data in this table was obtained from the editor of the Hawaiian Planters' Record.)

[2] H=Hawaii seedling.

Table I indicates clearly that the loss is due almost entirely to reduced tonnage. Diseased canes are uniformly much lighter than healthy canes of the same variety.

During the early part of the present year the mosaic disease was discovered by the writer at three different points in Cuba, apparently as the result of separate importations. At Cienfuegos it has been present for nearly 20 years, but as a result of discarding diseased plants in the seedling and propagating fields because of their unthrifty appearance, and perhaps partly owing to the fact that a proper agent of transmission was not present or at least not abundant in this region, it has spread very little. At Santiago de las Vegas it was found on plants recently imported from Louisiana and from Tucuman, Argentina. The latter plants had come originally from Java. The disease had spread from these plants to an adjoining field of the native Crystalina cane. In view of this demonstration of its ability to spread at Santiago, it is very fortunate that the diseased plants were early observed and destroyed. A slight infection has been found at Mercedes, also as the result of a recent importation.

Infected cuttings have been received in both Porto Rico and Cuba from Tucuman, Argentina, but to what extent the disease is prevalent in Argentina has not been learned.

Last year the mosaic disease was found in abundance at La Romana and the city of Santo Domingo, Santo Domingo, and less plentifully at Samana, La Vega, Monte Cristi, and Bonao.[1] Lastly it was discovered at St. Croix, Virgin Islands, on cane imported from Porto Rico.[1]

DISTRIBUTION IN THE UNITED STATES.[2]

The presence of the mosaic disease in the United States was first suspected when an agent of the Office of Sugar-Plant Investigations of the United States Department of Agriculture discovered young diseased cane in Porto Rico from seed cane imported from Louisiana. The plants were so young at the time that secondary infection seemed improbable, and it was assumed that the seed pieces were diseased when shipped from Louisiana. Accordingly another agent of the same office visited Louisiana and on July 7, 1919, confirmed the presence of mosaic there. The State authorities were apprised of this important disclosure, and the Government agent made a hurried reconnoissance of the Gulf States, which revealed the fact that the disease was already quite widely distributed there.

On account of the infectious nature of the malady and the fact that it has caused severe losses in other cane countries, a complete survey of the Southern States was immediately instituted to determine the location of all infested areas and, if possible, to trace the original importation of the disease and the course of its subsequent spread. Infested areas have been well delimited. The disease has been found by inspectors of the United States Department of Agriculture in Louisiana, Florida, Georgia, Alabama, and Mississippi (fig. 1). It is most abundant in Louisiana, as would be expected. There the river district is already badly infested. As far north as Angola, in West Feliciana Parish, several fields in a large plantation were found

[1] Stevenson, John A. The mottling disease of sugar cane. *In* Jour. Dept. Agr. and Labor, Porto Rico in press).

[2] Thanks are due to Mr. W. G. Taggart, vice director of the University of Louisiana Sugar Cane Experiment Station, and to Dr. C. W. Edgerton, pathologist, Louisiana Experiment Station, for courtesies extended to the writer and suggestions facilitating the survey in Louisiana.

in which 75 per cent or more of the plants had the mosaic disease. From this point south to Donaldsonville, however, the amount of infection is not heavy. Many plantations are entirely free from mosaic, so far as can be determined by inspection. From Donaldsonville to New Orleans an increasing amount of infection was recorded by the inspectors. Between Lutcher and Reserve, about 75 per cent of the plants in every plantation were infected. This is by far the most heavily infested large area in the United States. From this region to New Orleans and from New Orleans to the lower extremity of the river district the amount of infection ranges from 4 to 30 per cent. Just a few fields were visited where no mosaic was found.

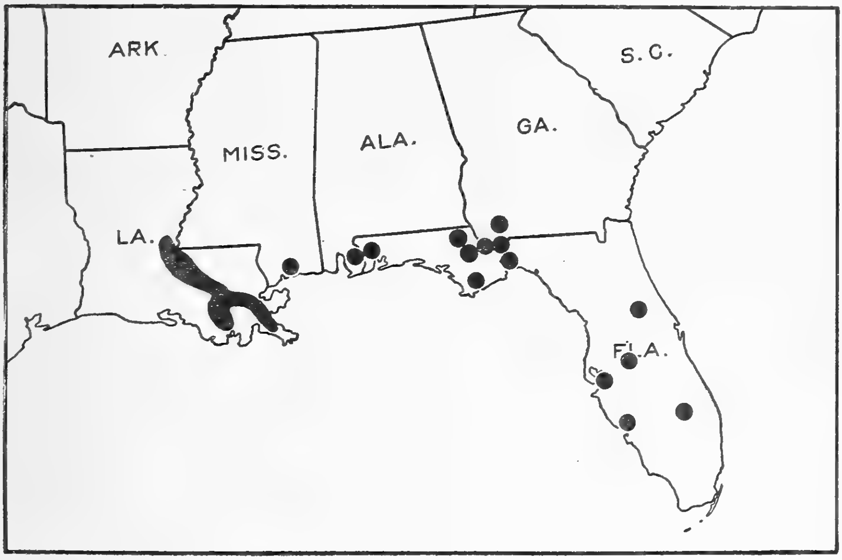


FIG. 1.—Map showing the location of diseased areas of sugar cane in the United States.

In the Bayou Lafourche district mosaic was found in only about one out of four fields visited and where present amounted to only 1 to 8 per cent of the plants. In the Bayou Teche district no mosaic was found on plantation cane, although nearly 500 fields were carefully inspected. A few cases were found in this region on cane recently distributed by the State Sugar Experiment Station. The immediate destruction of these few sources of infection is a matter of great importance. No mosaic whatever was found west of Bayou Teche or in Avoyelles and Rapides Parishes to the north. Thus, a very considerable part of the sugar-cane lands of Louisiana is still free from the disease, and every effort should be made to keep it free.

In Georgia the worst infested region is in the vicinity of Cairo, Grady County. There the proportion of infection ranges from less than 1 to 75 per cent or more in fields where the disease is present, but only about one-fourth of the cane fields in this county harbor the infection at all. The affected area is quite sharply delimited, all of the disease being confined at present to farms located on the highways leading out from Cairo. The cane fields in Georgia consist usually of a few acres grown for sirup making. It is quite possible that by prompt and energetic action this community could free itself from the mosaic disease in short order.

Cane fields are distributed over practically the whole State of Florida, but the crop is grown largely for sirup for home use and the cane patches are even smaller than those in Georgia. Mosaic has been widely scattered over the State by the distribution of cuttings from experimental plats grown for the purpose of testing varieties. There are only two points, however, where the disease has spread so as to include any considerable area, namely, the vicinities of Marianna and Bristol. Other points in Florida where mosaic has been found include Apalachicola, Tallahassee, Punta Gorda, Palmetto, De Land, Winterhaven, Chattahoochee, Muscogee, and Canal Point. These are all purely local infections, and in some cases the disease has not yet spread more than a few rods from the original plantings shipped in from other States. An eradication campaign would be entirely practicable in Florida.

Mosaic has been discovered at only one point, Biloxi, in Mississippi. From the farm on which it first appeared it spread to one other farm in the vicinity.

In Alabama similarly, it was found only on one place, near Muscogee, Fla. It was confined to the farm where it first appeared.

Final reports on the results of the inspection in Texas must be deferred, since the survey is still under way in that State.

The survey has also been very illuminating concerning the probable time of introduction of the disease into this country and the method of its subsequent spread here. Since 1913 a prohibitory regulation has been placed upon the introduction of sugar cane into the continental United States, and it is probable that no cane has been introduced since that time. Prior to 1913 varieties of sugar cane were imported many times by private individuals and by various Government agencies. The Sugar Experiment Station of the Louisiana State University, at Audubon Park, has been particularly active in importing new varieties, with the idea of securing some higher in sugar content and yield than those already grown here. Whether the mosaic was introduced by the experiment station or by private individuals no particular blame attaches to those who are responsible for the importation of this obscure disease. There is no known method by which the presence of the disease in cuttings can be positively established. It is merely pointed out that such an importation would be practically impossible with the present quarantine against sugar cane. Concerning the probable time of the importation that was responsible for the present wide distribution of mosaic in America, the survey has brought out the fact that the distribution of cuttings by the Louisiana Sugar Experiment Station in 1914 and prior to that time has not resulted in establishing the disease at the points where such cane was received. Since 1914, however, every point receiving seed from the station has become the center of a larger or smaller infected area. The inference, of course, is that while the disease may have been present at the station for a few years prior to 1914, it had not become so widespread that every seed shipment from there contained some infected cuttings. At the present time, about 97 per cent of the cane plants at the station have the mosaic disease. It is probable that private individuals have imported cane with this disease, but such cane is not likely to be widely distributed, and its spread, therefore, must depend upon natural agencies, a much slower process.

Without exception, every infested area in Georgia and Florida can be directly traced to distributions of seed cane from the Sirup Field Station at Cairo, Ga., since 1916, and the infection at this station dates from the importation of a number of varieties from Audubon Park in 1915. In nearly every instance where diseased cuttings have been received from Cairo, it has resulted in secondary infection of the surrounding native cane.

The above is the brief and much condensed compendium of a large amount of data collected during July, August, and September, 1919. It has made possible the recommendation of plans of attack upon the mosaic disease, which vary slightly in the different cane regions of the country, but all of which, if strictly adhered to by every cane planter, will bring the disease under control. Its capacity for rapid spread, as demonstrated in Georgia and Florida, means that a lapse of one year will result in immeasurably complicating the problem of ultimate eradication.

LOSSES IN THE UNITED STATES.

Since the mosaic disease had been unrecognized in this country until the writer announced its presence in July of this year, no extensive data have been accumulated to determine whether the losses caused by it in the United States are comparable with those sustained in Porto Rico. A few figures (Table II) have been obtained in Louisiana, however, which indicate that we may expect a decrease in yield almost equal to that in Porto Rico if the disease is permitted to become as widespread here as it is in that country. Losses here are held in check somewhat on account of frequent replanting. It has been noticed that where infected sugar cane is allowed to ratoon over a long period of years that losses due to the mosaic are more severe each successive year. The figures in Table II were obtained by cutting all of the cane in approximately square patches of about one-tenth to one-fifth of an acre selected in commercial fields and in the fields at the Sugar Experiment Station, Audubon Park, La. The stalks cut from such patches were then sorted into two classes, diseased and healthy, and the average weight of stalks in each class was determined. The patches were not selected at random, but an attempt was made to find areas where the mosaic was doing a maximum amount of damage and at the same time a sufficient number of healthy plants were present in the patches, growing under identical conditions, in order to make a fair comparison possible. Since, if no attempt is made to control the disease in these fields, we may expect ultimately to find an infection of 100 per cent, the losses will then be equivalent to the figures found in column 5 of Table II.

TABLE II.—*Tests of sugar cane in Louisiana, showing the extent of losses in different varieties.*

Variety.	Number of stalks—		Average weight of stalks—		Reduction in weight of diseased stalks.	Diseased stalks in field.	Loss in tonnage.
	Healthy.	Diseased.	Healthy.	Diseased.			
			Pounds.	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
Louisiana Purple	330	160	1.13	0.7	38	32	12.16
Louisiana Striped	268	100	1.507	1.22	19	27	5.13
D-74	204	108	1.27	1.03	18	34	6.12
D-95	348	136	1.65	1.16	29	28	8.12
L-511	373	310	.874	.787	10	45	4.5

PRIMARY SYMPTOMS.

Upon walking between the rows of cane in an affected field, more or less plants will be seen that are conspicuous on account of a general pallor of the leaves. This may be discernible for many rods. Closer examination of such plants reveals that the pallor is due to irregular light-colored streaks or spots on the leaves. The affected leaf areas, in so far as color is concerned, are of two distinct types. The most common type presents merely a "washed-out" appearance. It is, in fact, merely a tint of the normal color, in which the blue and yellow are present in the same proportions but diluted. In the second type, the yellow is predominant, and the affected areas have a decided yellowish green appearance. The normal and affected areas are sharply demarked. In other words, there is no gradual merging of one color into the other. There is a great diversity of patterns in the different varieties, due to the variation in the amount, size, and shape of the light-colored areas, but the arrangement is so constant in any particular kind of cane that the character could be used as an aid in determining varieties.

Among the cane varieties commonly grown in Louisiana and other Southern States, some rather constant differences occur in the expression of the mosaic disease. In L 511 it will be noticed that streaks are rather scant in newly invaded leaves and on account of their light color make a great contrast with the normal areas. They are bluntly pointed and range from one-sixteenth to three-sixteenths of an inch wide and from one-fourth of an inch to 3 or 4 inches long (Pl. I, fig. 4). Later, the light areas or streaks are more numerous and in most cases tend to become confluent in well-defined bands of light tissue extending across the leaf at right angles to the midrib and alternating with bands where the light streaks remain isolated. These bands are from 1½ to 2 inches long. The above condition is typical of the disease as it appears in L 511, but does not invariably occur.

In D 74 the streaks are not usually isolated, even at first, so that very quickly the coalesced light areas are predominant and the normal areas appear as irregular, elongated islands 1 thirty-second to three-eighths of an inch wide and of varying length, from one-fourth of an inch to several inches, as shown in Plate I, fig. 5. Affected areas are light green at first, but the tendency for the whole leaf to become opaque yellow is pronounced.

In purple cane the light areas are elongate and isolated at first, but later they predominate and coalesce and the normal green shows as irregular elongated islands, as illustrated in Plate I, fig. 5. The islands are not of uniform width or length.

In the youngest leaves of Ribbon cane, the light areas are in the shape of attenuated streaks, usually about one-eighth of an inch wide and one-half of an inch to 1½ inches long, but the size varies greatly, some streaks being very minute, and others, by running together at the ends, form continuous stripes 6 inches or more in length. In general, the streaks are isolated from one another and uniformly distributed on the leaf blade as in Plate I, fig. 4. The amount of normal-colored tissue greatly exceeds the light tissue at this time. Exceptionally, the light streaks may be confluent from the first, and this is more frequently seen near the midrib, leaving the margin normal in color or with a few scattered pale streaks. In slightly older leaves, by growth and confluence of the light-colored areas the latter becomes predominant and the whole leaf becomes pallid or even yellow in its general appearance. The dark-green or normal areas are now very scant, and they appear as elongated streaks in the pale green, just the reverse of the condition in young leaves, except that the dark-green streaks are less regular in outline. The individual streaks vary considerably in width and direction throughout their extent, streaks perhaps three-eighths of an inch wide at one end becoming constricted to 1 thirty-second of an inch, then alternately widening and narrowing or becoming oblique with the midrib, with no apparent forces limiting their extent or direction except that in general they are elongated in the direction of the parallel veins of the leaf.

In D 95 the light areas are predominant from the start (Pl. I, fig. 5).

In L 219 the light streaks are isolated near the base of the leaf but become confluent toward the tip.

In L 226 the streaks are isolated and even in older leaves remain so.

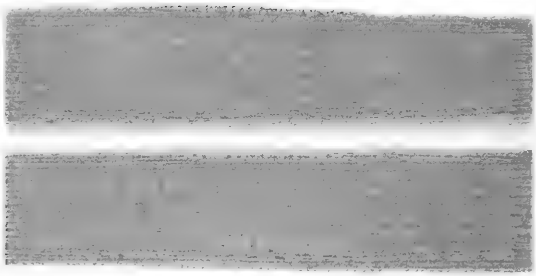
L 231 is very severely injured. The leaves are usually quite yellow, as shown in Plate I, fig. 6. Practically the entire surface is light from the beginning. There are exceptions, however. The amount of injury in this variety is variable.

L 253 is quite tolerant. The lighter areas predominate but are not yellowish. All plants seen were dark green and vigorous.

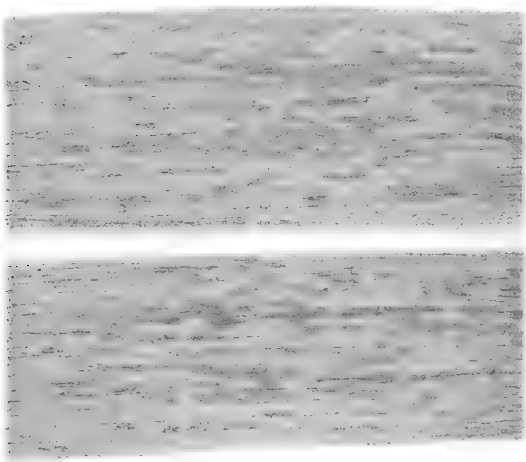
SECONDARY SYMPTOMS.

Field observations covering a number of years indicate that the deleterious effects of the mosaic disease are cumulative. The streaking and spotting of the leaves discussed above are the only noticeable sign in newly infected plants. The disease is never fatal during the first year and, in fact, it rarely terminates in death even in diseased plants that have been allowed to ratoon for years. Usually, however, more serious effects are seen in first ratoons of cane which became infected the previous year or in plant cane originating from diseased cuttings. At this time another quite distinct leaf symptom appears. It consists of small white opaque spots and streaks in the light-colored areas. These streaks are smaller than the light areas previously mentioned and differ from them in having no pigment whatever. They range from mere points to elongated irregular streaks several inches in length. The white streaks may become confluent to a limited extent. They are for the most part restricted to the light-green areas of affected leaves, but do not correspond to them in outline and typically remain more or less isolated from one another. The white opaque tissue has a dried-out appearance and seems to be quite functionless. It remains firm, however, and does not become brown or rot out. The amount of total leaf area occupied by this type of tissue rarely exceeds 20 to 30 per cent of the whole.

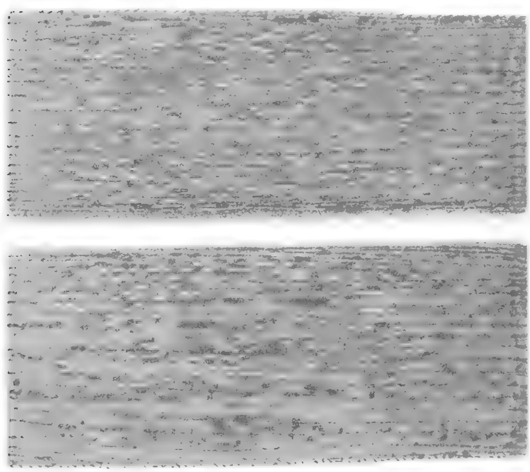
At about the same time, or during the next year, a still more injurious sign of mosaic appears, namely, the striping or cankering of the stalk. This is much more marked in some varieties than in others. Ordinarily, it does not become noticeable until the cane is quite well developed. By tearing away the enveloping leaf bases, cankers can sometimes be found in the incipient stage. They appear as discolored or water-soaked patches or longitudinal streaks on the internodes. In severe cases these areas become sunken and the internodes are spindle shaped and attenuated. Longitudinal cracks may appear, resulting in the drying out of the cane. There is a tendency toward shortening of the joints and premature development



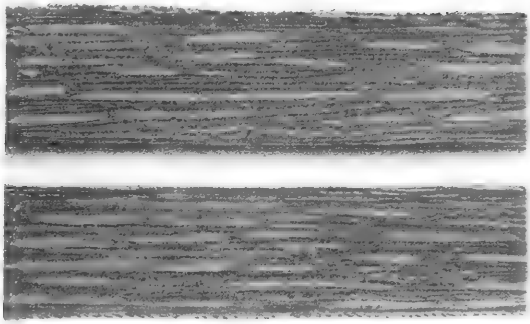
1.—A short piece of healthy leaf of the immune variety Kavangire.



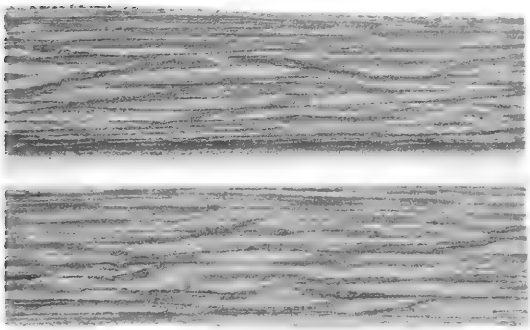
2.—A piece of leaf of variety B-3922, showing isolated, more or less rounded and irregular patches of normal color on a background of pallid, affected tissue.



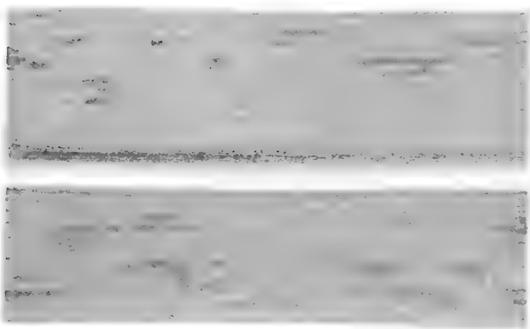
3.—A piece of leaf of variety D-117, showing a mosaic pattern somewhat similar to the above, but finer.



4.—A common type of mosaic, irregular streaks of pallid green, of unequal length and width but elongated in the direction of the long axis of the leaf, on a background of normal green; on leaf of variety Rayada.



5.—A pattern somewhat similar to the above, but with the colors reversed, so that the pallid green predominates; on leaf of variety G. C. 1479.



6.—The most injurious of the common types of mosaic. Just a few streaks or islands of normal green remain on a background of yellowish green; on leaf of variety M. P. R. 2.

of roots and shoots at the nodes of standing cane. Figure 2 shows such a condition in Yellow Caledonia cane. The photograph reproduced here was taken at Arecibo, Porto Rico, in 1919, and the probabilities are that the plant had been infected for at least five years. These identical cuttings and similar ones were brought to Washington and planted in a quarantine greenhouse. Most of them grew, but at the present time, five months after planting, they are scarcely 1 foot tall. The opaque white streaking covers practically all of the leaf area. This is the most excessive injury ever observed by the writer. Most varieties of cane do not go to pieces like this, but rather the injury to stalks consists merely of retarded development. Among the well-known varieties, however, all gradations in the extent of injury between these two extremes are to be found.

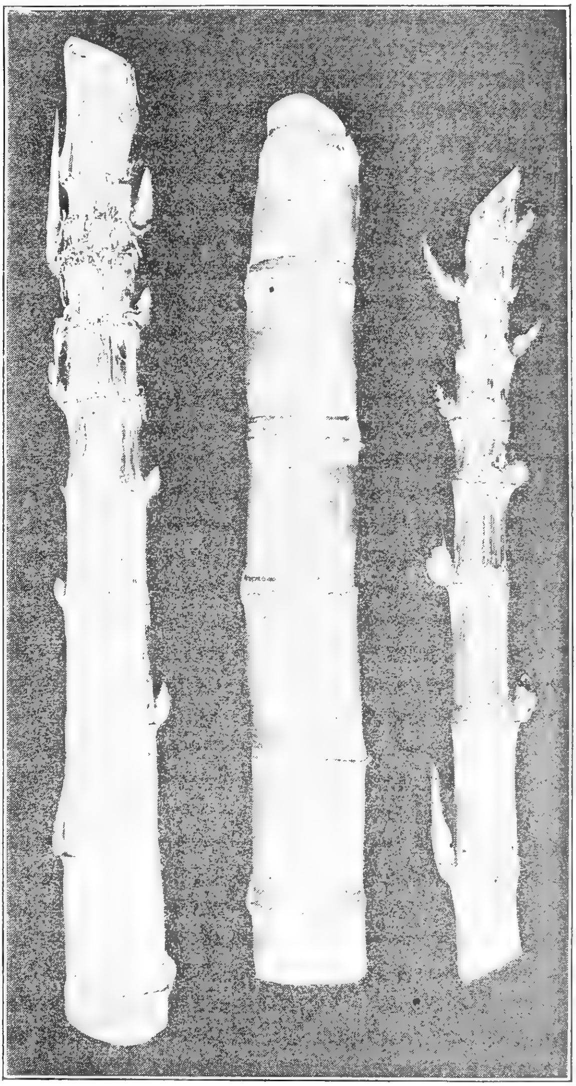


FIG. 2.—Canker stage in Yellow Caledonia sugar cane; healthy cane of the same variety in center.

When a large proportion of the plants in a field are infested, the aspect in general resembles the effect of a severe drought. The foliage of the entire field is yellowish, and the plants are more or less noticeably stunted. Where a row of some immune variety is planted in or near a badly infested field, the contrast in color is exceedingly conspicuous and the dwarfed habit of infected plants is more noticeable. It is possible to recognize such fields from a distance of half a mile or more on account of their sickly, dry appearance.

INJURIES RESEMBLING MOSAIC.

Many types of injury are commonly found on cane leaves that might be confused with this malady by one not familiar with it. The condition termed chlorosis, which is due for the most part to soil conditions, expresses itself in many ways, some of which closely simulate the mosaic disease. The affected areas are white opaque or yellow, and the most familiar form is a regular striping of the leaves longitudinally. The stripes usually extend the entire length of the leaves and may be about one-eighth of an inch wide and numerous, with normal green stripes of equal width spaced between them, or the chlorotic areas may be quite wide. Occasionally, the entire leaf is pure white. Less frequently the areas are in the form of large spots or blotches, extending inward from the margins of leaves or situated at the center of the blades anywhere from base to tip. Another type, which is rare, consists of a very fine irregular white mottling of the leaves, which, however, is in local patches and does not involve the whole leaf, as is invariably the case with the mosaic disease. Many fungi cause spotting of the leaves of cane, but these can easily be distinguished, as the spots usually turn brown and the leaf tissue dies, which does not occur in the cane mosaic. Since a pale-green halo is sometimes present surrounding these small spots, they have the appearance of mosaic from a distance, especially when quite numerous, but a close examination always reveals quite distinct differences. Many insects, especially those which feed by puncturing the leaf epidermis and sucking the sap from the layers of cells below, cause a very fine mottling of the leaves when the punctures are present in enormous numbers. Ordinarily, the punctures are scattered and can lead to no confusion. This type of injury can also be determined by close inspection, since the minute pale area surrounding each individual puncture is almost exactly circular and has no tendency to elongation in the direction of the long axis of the leaf, such as is almost invariably the case in true mosaic. Drought, lack of proper nutrients in the soil, excessive rainfall, and poor tilth, or combinations of these, sometimes result in a general pallor or yellowing of the leaves, but this color is always uniform and can lead to no confusion.

VARIETAL SUSCEPTIBILITY.

VARIETIES ATTACKED.

More than a thousand varieties of cane have been determined to be susceptible to the mosaic disease. Most of these are the progeny of seedling canes that exist in small variety-test rows or patches at the various sugar-cane experiment stations, but the list includes also practically all of the commercially esteemed sorts grown for the mills on a plantation scale.

So far as can be learned, none of the varieties grown in Java is truly immune, but a high degree of resistance or tolerance of the disease has been observed in the favorite Java seedling canes grown in Porto Rico, a probable explanation of which has already been given. Only Java 56, 100, 228, and 234 have been seen by the writer in Porto Rico, but all of these, though 100 per cent of the individuals were affected, made a thrifty growth and produced apparently normal stalks. The leaves are not noticeably yellowed, but on the contrary appear to be of uniform dark-green color when viewed from a distance. Close inspection, however, shows the characteristic streaks, but the diseased areas are very little lighter than the normal areas. Probably the damage done to an individual plant is slight, but the aggregate damage to all of the individuals in a field is a measurable quantity and has been shown to be quite considerable in Java. In the different varieties all degrees of tolerance are exhibited, ranging from the highly resistant Java canes down to the soft white Otaheite or Bourbon cane, which is so severely injured that the cane is hardly worth milling. In addition to the conditions which might be termed varietal tolerance of the disease, some varieties exhibit decided and rather constant differences in the percentage of individuals that become affected under the same conditions. This is brought out in variety-row tests where the same varieties have been planted at several points in the same field. Under these conditions it has been found that some varieties will show a 100 per cent infection of the individuals in all of the rows, while in others perhaps only 60 per cent of the plants will be diseased in each of the separated rows or plats. It seems reasonable to suppose that all varieties were equally exposed to the contagion in such situations. This fact indicates a possibility of resistant strains among the individuals of a variety.

The Rayada or Striped cane and the Crystalina or White Transparent, the two favorite varieties in Porto Rico, are severely injured. Yellow Caledonia is grown on a large scale in some localities, and plants of this variety killed by the mosaic disease have been observed. This is quite unusual, since attacked plants of most varieties become badly stunted but do not die. All seedling canes from Demerara and Barbados grown in Porto Rico are attacked. Seedlings of the Insular and Federal agricultural experiment stations likewise are all affected, as are the seedlings originated at Centrals Guanica and Fajardo. Among the varieties planted commercially to a limited extent the Bambu, Cavengerie, Morada, and, in fact, all the broad-leaved canes have proved to be susceptible.

In Cuba all varieties that are exposed seem to become infected, but since the disease has not become rampant nor spread over any considerable area no opportunity to observe the reaction of all the varieties grown there is to be had. Practically all of the seedlings originated in the Harvard Experiment Station near Cienfuegos were affected, as well as the imported Java 228, L 511, and the native Crystalina at Santiago de las Vegas.

Practically all varieties are attacked in the Hawaiian Islands, and extensive damage is done.

The common varieties in Louisiana have proved susceptible to mosaic disease. Louisiana Purple, Louisiana Striped, D 74, D 95, L 511, L 218, L 219, L 226, L 231, L 253, and hundreds of seedlings being tested at the Louisiana Sugar Experiment Station all fall prey to the ravages of this disease.

IMMUNE VARIETIES.

Fortunately a few varieties of sugar cane have been discovered which appear to be entirely immune. Most of them are of the slender North India type, generally known as Japanese canes. The Kavangire, a variety which, because of its prolific stooling, yields a very large tonnage and is much esteemed in Argentina for making sugar has never been observed to be diseased, although it has been exposed to infection for four years in the worst infested regions of Porto Rico.[1] It is a rather long season cane, however, and for this reason is probably not suited to Louisiana conditions. Another Japanese cane, Cayana 10, which is becoming prominent in the sirup sections of Georgia and Florida, is also immune. This variety has already met with considerable favor on the part of cane growers in Georgia. All the other Japanese varieties observed, including many imported by the Office of Foreign Seed and Plant Introduction of the Bureau of Plant Industry, have been found to be uniformly free from this disease.

Among the broad-leaved thicker stalked varieties several kinds have been found that appear to be immune, but our evidence of their immunity is not so complete as is the case with the Japanese varieties. Louisiana seedlings 1646, 1606, 1674, and 1797, growing in the variety test plats at Audubon Park, New Orleans, this year appeared to be immune. No individuals of these varieties were diseased, although they were surrounded by other varieties, the individuals of which averaged 97 per cent diseased.

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[1] Townsend, C. O. An immune variety of cane. (Abstract of an article by F. S. Earle.) *In* Science, n. s., v. 49, no. 1272, p. 470–472. 1919.

OTHER HOSTS.

A number of other grass plants are known to be subject to the mosaic disease, but apparently they are attacked with difficulty and only under conditions favorable to the disease. Among these hosts are corn, sorghum, rice, millet, crab-grass, foxtail, and Panicum. Probably the list of susceptible plants is much larger, but up to the present time opportunity for testing others has not been had. In the case of corn, rice, and millet, we have no experimental proof that the diseases are the same, but must depend upon field observations. If not the same, the disease must be very similar, since the leaf symptoms are identical. The characteristic streaked and spotted appearance of the leaves is present in all attacked plants.

With regard to sorghum, crab-grass, foxtail, and Panicum our evidence is conclusive and proves that the infectious material or virus is the same for all of these plants. Sorghum seed of the Early Amber, Sugar Drip, and Japanese Ribbon varieties was sown in a bed at the quarantine greenhouse at Washington, where diseased plants of 17 different varieties of sugar cane were growing. When the sorghum plants were about half grown, practically all of them began to produce mottled leaves and continued to do so until they went to seed.

The seed was saved from these sorghum plants to determine whether the disease is transmitted to the next generation in the true seed.[1] The leaf symptoms in these greenhouse plants were exactly like the symptoms on sugar-cane leaves. Plants arising from the same batch of seed used in the greenhouse experiment cited above but planted elsewhere and not exposed to the disease did not show the phenomenon but produced healthy leaves of uniform color. The crab-grass, foxtail, and Panicum came up as volunteer plants in the quarantine greenhouse. Scores of stools of these weeds were allowed to mature for observation and identification. Every plant became infected and exhibited the typical leaf symptoms. Some half dozen other species of wild grasses were present in the greenhouse, but they were not attacked. All of the wild grasses were abundant outside of the greenhouse, but in spite of an assiduous search in the vicinity not a single infected plant could be found. The conclusion to be drawn from these observations is obvious. We are not dealing with similar mosaic diseases of these various graminicolous hosts, the viruses of which are specific for each host, but with one and the same disease.

The existence of other host plants, especially the common wild grasses, would appear to be one of the most alarming of the recent developments in the problem. It is needless to say that the control

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[1] This seed was planted in flats. At the present time, three weeks after germination, no sign of the mosaic has appeared.

of the disease would be immeasurably complicated if it were to become prevalent on such omnipresent weeds. Fortunately, however, our observations appear to indicate that the grasses other than cane become infected only under conditions favorable to the disease and in the near vicinity of infected sugar-cane plants. Infected corn, for instance, has been seen by the writer only in Porto Rico, where it was growing between the rows of diseased cane stubble. Infected rice plants were observed there only once, growing just across a narrow dirt road from a badly attacked cane field. At Audubon Park, La., attacked sorghum was seen in a similar situation, the most remote plants being only about 3 rods from the cane, and the percentage of attacked plants decreased in an inverse ratio to the distance from the cane. The same was true of crab-grass, which was abundant in the sorghum field. These observations are encouraging and tend to offset the disconcerting facts discussed above.

NATURE OF THE DISEASE.

INFECTION PHENOMENA.

Sugar-cane mosaic is an infectious chlorosis, similar in many respects to the mosaic diseases of tobacco, cucumber, bean, tomato, and potato. Evidence of its infectious nature exists in hundreds of field observations and in the infection of experimental plants under controlled conditions. The well-defined epidemic in Porto Rico, in which it has been established that the disease started in a small local area and gradually spread from this focus of infection, diseased plants being confined within the limits of the ever-increasing infested territory and not appearing sporadically at remote points, is convincing. It leads to the inevitable conclusion that some virus or inoculum is responsible for the appearance of new cases and that the only source of inoculum is some plant previously infected with the disease. No other explanation accounts satisfactorily for the observed facts. Climatic conditions were at first suggested, but the epidemic has lasted already for a period of years, during which rainfall, temperature, sunshine, and the other factors that go to make up climate have been normal. The wearing out of soils was regarded as a possible cause, but during the steady progress of the disease it gradually encroached upon every conceivable type of soil, including the richest and most productive in the island. Strong support was given to the idea that it was a case of deterioration or the "running out" of varieties, but when it became evident that all varieties present in the invaded district were affected, this idea was abandoned. For the same reason the hypothesis that it is a case of bud variations, or "sports," seems highly improbable, and when the regular progress of the epidemic is borne in mind, radiating outward as it does from a common starting point, there is seen to be nothing to substantiate this claim.

Only a few specific observations of infection may be cited in the limited space available. In October, 1918, healthy seed of about 80 varieties was brought into the infested area from disease-free regions in order to determine whether any natural immunity existed among the varieties present in Porto Rico. This seed was planted at the Santa Rita estate, near Yauco. When the seed germinated, the young plants were seen to be healthy and normal, but within six weeks to two months practically every plant of all varieties with one exception (the Japanese Kavangire) showed the unmistakable symptoms of mosaic. This was a clear case of secondary infection from the fields of diseased cane surrounding the test plat.

At Santiago de las Vegas, Cuba, about 200 seed pieces of Java 228 cane imported from Tucuman, Argentina, were planted in two rows, and two rows of the native Crystalina cane were planted beside them. The Java cane was 100 per cent infected when it came up, the cuttings having come from diseased parent plants. When this planting was examined in June, 1919, 75 per cent of the Crystalina plants were characteristically diseased. The Crystalina seed pieces had come from a field which was minutely searched and found to be entirely free from disease. No other cases were found in the entire region, in fact, with the exception of a single stool of L 511 imported from Louisiana.

In July, 1919, a field of D 74 stubble cane, grown for sirup near Cairo, Ga., was found to be healthy with the exception of one corner near the kitchen garden, where about 80 per cent of the plants had the mosaic. Investigation revealed the fact that a patch of green chewing cane had been growing adjacent to the D 74 at that corner during the preceding year. The green cane was found growing elsewhere on the farm this year, and examination showed that every plant had the mosaic disease. Clearly the D 74 had become infected last year, the disease had survived the winter in the stubble, and the shoots were diseased when they appeared again.

At Washington, D. C., 17 varieties of cane, all diseased, are growing in an insect-proof quarantine greenhouse.[1] From time to time healthy sugar-cane plants in pots have been taken into the greenhouse and left exposed to the contagion. Invariably they show the incipient symptoms of the disease on the average in 17 days, proving that the incubation period is from two to three weeks. As has been mentioned elsewhere, sorghum and wild grasses taken into this greenhouse have also become infected. Much more evidence of this kind could be adduced, but it is believed to be sufficiently clear that infection

[1] Insects were present in the greenhouse.

by some principle present only in dieased plants is responsible for the appearance of the disease in formerly healthy individuals.

TRANSMISSION OF MOSAIC IN DISEASED SEED PIECES.

Experiments in Porto Rico [1] and elsewhere have repeatedly demonstrated that cuttings from infected stalks invariably give rise to infected plants. The young shoots are seen to be mottled as soon as they appear. These are referred to as primary infections. The fact is one of far-reaching importance, and to it must be attributed the spread of the disease to new regions, remote from any infected cane, by shipments of cane seed. The use of diseased stalks for propagating results in wider distribution of diseased plants on the same plantation from year to year and insures the survival of the virus, even in the absence of secondary infections. Transmission of the disease in cuttings is a fact, the importance of which can not be overemphasized in view of its obvious bearing on control measures.

TRANSMISSION OF THE DISEASE BY CARRIERS.

It can be proved mathematically that by the law of chance the percentage of diseased plants in a plantation would tend to remain stationary from year to year provided there was no conscious or unconscious selection,[2] if the spread of the disease depended wholly upon the use of infected cuttings. Nature has provided a far more efficient method for the quick dissemination of the malady. Secondary infection, i. e., infection due to the inoculation of healthy plants during the growing season, goes on at a more or less rapid rate wherever the disease has been observed. Secondary infections are easily determined as such when the plants are young. In the case of plants infected in the greenhouse it has been determined that only the leaves which were immature at the time of inoculation and leaves subsequently formed become mottled. When a plant is found with normal leaves up to a certain point on the stalk and mottled leaves above that point it is a clear case of secondary infection. Since in older plants the lower leaves are gradually sloughed off until only a relatively small terminal tuft of the youngest leaves remain when the plant approaches maturity, this method is obviously limited to young plants or to plants with green leaves still present above and below the point of inoculation.

The rate of spread of the disease, as indicated by these secondary infections, varies greatly. Fields are frequently seen in which there has been apparently no secondary infection during an entire growing

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[1] Stevenson, John A. The "mottling" disease of cane. Porto Rico Insular Exp. Sta. Ann. Rpt. 1916–17, p. 40–77. 1917. [Literature], p. 76–77.

[2] Selection is employed where the disease is not recognized. During the beginning of the epidemic in Porto Rico, when sugar was bringing an unprecendented price, it was learned that the manager of one of the mills was instructed to grind the best cane and save the poorest for seed. The "poorest" was undoubtedly that attacked by mosiac.

season. As an extreme case illustrating this point, the fields near Cienfuegos, Cuba, may be cited. There the disease has merely survived by the planting of infected seed pieces, and secondary infection, if it goes on at all, is certainly very limited. Even in Porto Rico, during the height of the epidemic, secondary infection was at a standstill in some localities for a year or more. On the contrary, whole fields of healthy cane became infected in the short space of a month or two. Such a case was the invasion of the variety test field at Santa Rita, Porto Rico, previously mentioned. No doubt the explanation for this great variation in rate of spread by secondary infection must be sought in the mechanics of inoculation. Up to the present no positive proof of the method by which inoculation is accomplished in nature has been brought forward. Reasoning from the fact that new cases often appear at some distance from diseased individuals, it would seem that some agent or carrier is necessary. Mere contact of diseased and healthy plants does not serve to communicate the infection from the former to the latter. In no case has the planting of healthy cuttings in the same pots with diseased plants resulted in the new plants becoming diseased. The same holds true for plants in the field, where healthy plants are often seen with their leaves mingling freely with the leaves of diseased plants for a time much longer than the incubation period for mosaic, but with no evidence of transference of the inoculum. It is evident that special conditions are necessary in order that the disease can be communicated to healthy plants.

Field observations indicate that acceleration in the spread of the mosaic disease is accompanied with or preceded by severe insect infestations. The cane leafhopper (*Tettigonia* sp.) in particular has been noticed to accompany the rapid spreading of the disease. This evidence is incomplete, but it is supported by the fact that 10 healthy plants placed in insect-proof cages in the greenhouse at Garrett Park, Md., did not contract the disease, while five control plants outside of the cages, but otherwise under identical conditions, all became infected. Aphids were abundant on the diseased cane in this greenhouse, and a few leafhoppers were present. A great deal of experimental work remains to be done before formal proof of the responsibility of any particular insect or insects for the transmission of the disease can be offered.

SOIL RELATIONS.

There has been no indication that the contagion persists in the soil after a crop has been removed and the stubble plowed up. Fields that have been veritable hotbeds of infection after being plowed up and planted with clean seed have only a few scattered cases, which can be accounted for by faulty seed selection. Healthy cuttings planted in the soil of pots from which badly diseased specimens had just been removed grew without any evidence of the disease. The virus does not live over in the soil and it is doubtful whether it exists there at any time. In this respect the mosaic does not by any means present the practical difficulties in the way of control measures to be met with in root-rot. Root-rot, in fact, is to be regarded as a far more serious problem for the Louisiana cane planter than mosaic on this account.

RELATION TO DISINFECTANTS.

Treatment of infected seed pieces by soaking in strong Bordeaux mixture or corrosive sublimate previous to planting has had no effect on the course of the disease. All shoots were typically mottled as soon as they appeared. It was hardly to be expected that superficial disinfection could influence the virility of the infectious principle when all our evidence indicates that the latter permeates the internal tissues, or at least the vascular systems of affected plants.

RELATION TO FERTILIZERS.

Many experiments [1] have been performed in Porto Rico to determine the effect of applying fertilizers, since the claim was made by many planters that mosaic was due to insufficiency of plant nutrients in the soil. Filter press cake, sulphate of ammonia, and lime in various combinations, together with turning under cover crops and good tilth, had no noticeable effect on the disease as compared with control plats. Standard complete fertilizers were also tried. Beyond a slight stimulation in growth and the darker green color of the treated plants, there was no observed effect. Diseased plants may be expected to respond to good growing conditions the same as healthy ones, but the same constant difference between healthy and diseased plants is maintained under all conditions. The diseased stalks remain below the average weight for healthy stalks and are just as capable of spreading the disease. Liming the soil has no more effect on diseased plants than the application of fertilizers.

CONTROL.

It is interesting to note that in Java long experience has demonstrated that the disease can best be held in check by careful selection of healthy plants for seed and by replanting fields with cuttings taken from the same field, in preference to buying cuttings of unknown origin or moving the cuttings from field to field on the same plantation. The use of such methods practically amounts to tacit admission of the infectious nature of cane mosaic, although it is ascribed to "bud variation." The facts which have most impressed the Dutch planters are that cuttings from diseased stalks always

[1] Stevenson, John A. The "mottling" disease of cane. Porto Rico Insular Exp. Sta. Ann. Rpt., 1916–17, p. 40–77, 1917. [Literature] p. 76–77.

produce diseased plants and that careless importation of seed is apt to result in increased amounts of the disease.

In the Hawaiian Islands also the disease is controlled by selection of clean seed and the use of resistant varieties.

Measures for controlling the mosaic disease recommended in the following pages are not haphazard expedients, but have been used with very satisfactory results in Porto Rico for more than a year. Planters there have paid a heavy price to learn them, and it is urged that planters of sugar cane in the United States cooperate to prevent a possible epidemic. Indifference to the situation may result in the cane growers being confronted with the fact that it is too late to practice seed selection, as is already the case in western Porto Rico. At present, it will work no particular hardship on the planters to take steps that will reduce the disease to a minimum.

ELIMINATION BY ROGUING.

Roguing consists of pulling out infected plants, root, stem, and branch, and throwing them down between the rows. It is based on the fact that as soon as the plants are wilted they are no longer dangerous as a source of infection. This method is applicable only to fields in which the disease has not obtained a strong foothold. It is not recommended for fields in which the number of infected plants exceeds 5 per cent in half-grown to mature cane or 20 per cent in young plants just sprouting. The size of the field and the condition of surrounding fields with reference to the occurrence of the disease in them must also be taken into consideration. When the field is quite small or consists merely of a few rows or plants of a new variety being propagated for trial on a plantation scale, it should be rogued even if 100 per cent of the plants are infected. Such plants are a constant menace to plants in surrounding fields. In large fields where the proportion of diseased individuals is greater than 20 per cent, roguing is impracticable, not because the plants are any less potent as sources of infection, but because diseased plants produce millable cane, and to destroy considerable quantities of such plants would probably result in greater financial loss than would be sustained by the reduction in yield due to new cases. Large fields with a high percentage of diseased plants should be allowed to mature, but no cane from such fields should be saved for seed.

It is suggested that the following schedule of inspections and roguing be put into operation: In the spring, just as soon as all of the plants have sprouted, the fields should be inspected by passing up and down the rows. All diseased stools should be pulled out of the ground and cast down between the rows. If this first inspection is carried out in a thorough manner the field will be completely freed from the disease provided no secondary infections are going on.

Since there are as yet no certain means of determining the latter fact, a second inspection is essential. It should be made from 25 to 30 days after the first, a lapse of time sufficiently in excess of the incubation period for mosaic to insure recognition of the disease in plants inoculated prior to the first inspection. If no diseased plants are found during the second inspection, it can be assumed that secondary infection is not in operation and that the remaining plants will continue healthy. If diseased plants are found, however, it establishes the fact that secondary infections are going on. The field should be rogued as before, and a third inspection made after the same interval, i. e., 25 to 30 days. If the carriers remain active it may be necessary to repeat the process several times, and owing to the impossibility of recognizing the disease in inoculated plants before the end of the incubation period it is certain that plants which have become infected just before the inspection is made will escape detection. This emphasizes the necessity for making the first inspection early, preferably before leafhoppers or other sucking insects have appeared on the plants.

This procedure may result in perfect control or eradication of the disease or in partial control, the element of uncertainty being due to our inability to control the carriers. By it their activity can be rendered less effective by reducing the sources of inoculum to a minimum. It has effectually halted the progress of the disease into new territory in Porto Rico.

ELIMINATION BY GRINDING ALL CANE AND SECURING CLEAN SEED.

In badly infested sections the problem is manifestly complicated. Where 25 to 60 per cent or more of the plants in large fields are diseased, roguing is obviously out of the question. Such plantings should be allowed to mature. Every stalk of it should be ground, however, and the stubble plowed up and killed. This means, of course, that carefully selected seed must be imported for replanting. Fortunately there is still an abundance of healthy stock in Louisiana and other cane sections in the United States. As a result of its recent exhaustive survey for mosiac disease, the Office of Sugar-Plant Investigations of the Bureau of Plant Industry is in a position to furnish information on the nearest or most accessible source of clean seed for any region. Data have been secured on the prevalence of other diseases and insect pests in all cane regions, so that reasonable security against the dissemination of other cane maladies is assured.

EXCLUSION.

There are at the present time (October, 1919) a number of large cane areas in the United States not yet invaded by the mosaic disease. Cane planters in these areas should urge the enactment of

State legislation prohibiting the importing of cane into them from any source whatever until such time as it can be accompanied by an authentic certification of health. Such areas include the entire Bayou Teche district and the parishes to the north in Louisiana, consisting of St. Mary, Iberia, Vermilion, Lafayette, St. Martin, Acadia, St. Landry, Avoyelles, and Rapides. This is, of course, the most important disease-free area. (Fig. 2.) Other similar

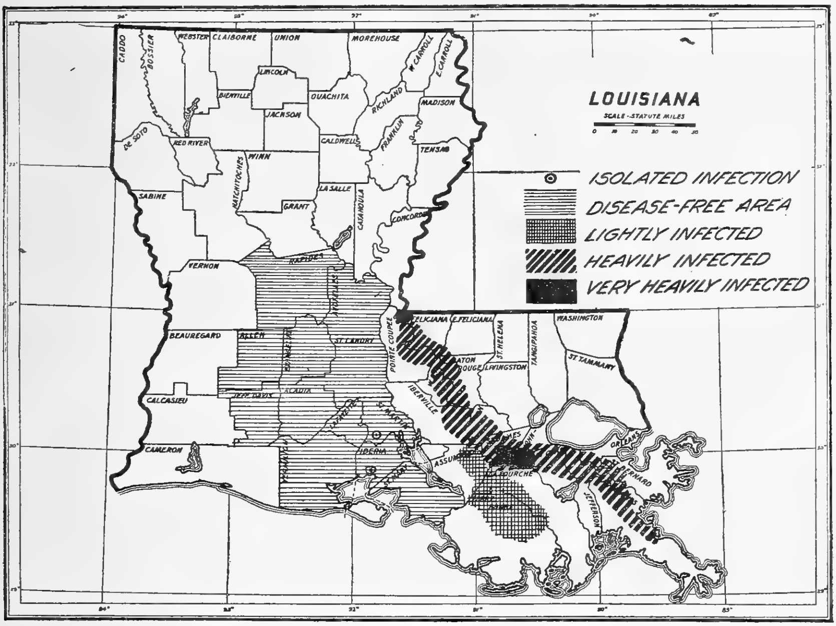

FIG. 3.—Map of Louisiana, showing the location of diseased areas of sugar cane in that State.

areas are the entire State of Mississippi with the exception of Biloxi; the entire State of Alabama except a small locality near Muscogee, Fla.; the entire State of Georgia except Grady County; and all parts of Florida other than those indicated in figure 4.

ERADICATION.[1]

Where the disease is present in small amount and in few well-defined areas, the possibility of quick and complete eradication exists. Such conditions are found in Mississippi, Alabama, and Florida. (See fig. 1.) The cane in these areas should all be ground during the present harvesting season and the stubble plowed up. As a precautionary measure, some crop other than a grass should be grown on the land for one year, after which cane may again be grown with safety. The two small infested areas in Alabama and

[1] In so far as it applies to the regions indicated, we concur in this suggestion by Mr. Wilmon Newell, Plant Commissioner of Florida.

Mississippi offer no difficulty at all. They can be destroyed with practically no loss to the owners, and the assurance of healthy crops in the future more than offsets the inconvenience of growing some other crop on the land now occupied by infected cane. The success of the measure in Florida is made possible by the present organization of the State plant board, which has already met the test of successfully handling more serious problems.

ELIMINATION BY PLANTING IMMUNE VARIETIES.

Success of the control measures suggested up to the present depends entirely upon the whole-hearted cooperation of all cane growers.

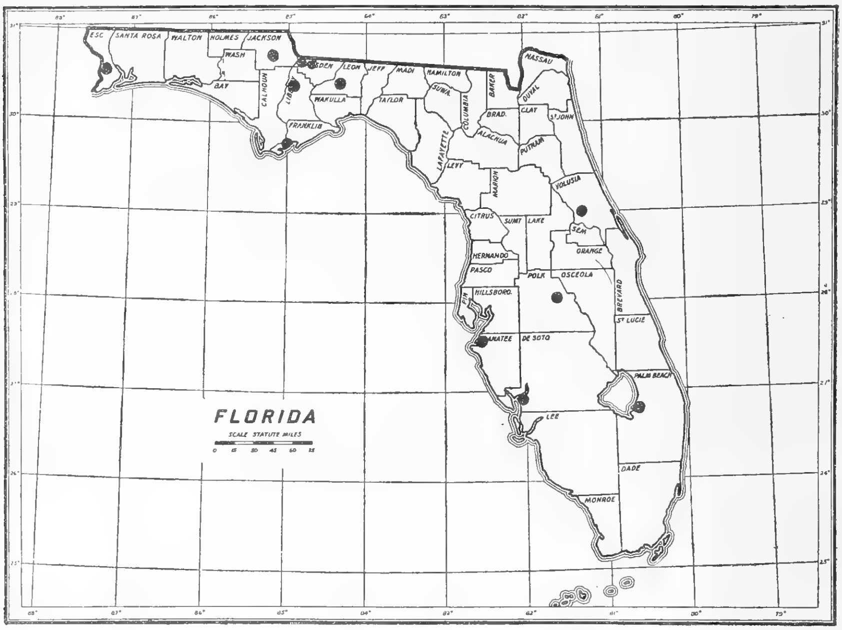

FIG. 4.—Map of Florida, showing the location of diseased areas of sugar cane in that State.

There yet remains a method, applicable only to certain regions, by which a planter can make himself wholly independent of any default on the part of his neighbors. A few varieties of sugar cane have been discovered that are absolutely immune to mosaic under all conditions. Most of them are of the type referred to as Japanese cane. Their origin is obscure. They have certain characteristics in common. All are tall growing with slender stalks. They stool abundantly, ratoon well, and produce an enormous tonnage. The sucrose content is not so high as in some of the broad-leaved canes, but in sugar per acre they take first rank with the best existing varieties. The Kavangire, Zwinga, Uba, Cayana 10, and numerous others imported by the office of Foreign Seed and Plant Introduction are included among these varieties. The Cayana 10 has already won a well-deserved popularity among the farmers of the cane-sirup section in Georgia and northern Florida on account of its high tonnage and the excellent quality of sirup made from it. The Kavangire is used for manufacturing sugar in Argentina. Its estimable qualities are brought out in Table III.

FIG. 5.—Kavangire sugar cane (immune), at the left; G. C. 1070 (susceptible), at the center; Java 36 (susceptible but tolerant), at the right.

TABLE III.—*Yield and analysis of Kavangire sugar cane compared with other standard varieties.*[1]

Variety.	Average weight of single canes.	Weight of cane per hectare.[3]	Brix scale.	Sucrose.	Purity.	Weight of sugar per hectare.[3]
	Kilos.[2]	*Kilos.*[2]	*Degrees.*	*Per cent.*	*Per cent.*	*Kilos.*[2]
Kavangire	0.68	166,850	17.84	15.68	87.5	16,090
Java 36	1.36	117,300	17.55	15.34	87.4	11,024
Java 213	.84	95,725	17.54	15.79	89.96	9,533
Louisiana 60	1.87	118,125	17.32	15.34	87.05	10,973
Java 139	1.10	89,975	16.67	14.41	86.40	7,853
Rayada (Louisiana Striped)	1.71	94,150	18.26	16.39	89.74	9,714
Java 234	.95	75,550	19.02	16.66	87.08	7,703
Morada (Louisiana Purple (?))	1.28	72,925	16.69	14.54	87.07	6,354
Honduras	1.23	76,575	16.98	14.36	83.88	5,998
Java 100	1.00	79,675	16.03	13.57	89.68	6,456
Tamarin	.95	33,325	19.15	17.50	91.54	3,940

[1] Bennett, A. G. Informe de subestaciones para el año 1914. *In* Rev. Indus. y Agr. Tucuman, año 5, p. 208-209. 1914.

[2] A kilo is the equivalent of 2.2 pounds.

[3] A hectare is the equivalent of 2.47 acres.

Figure 5 shows a row of Kavangire cane on the left; a susceptible variety, G. C. 1070, at the center; and a diseased but tolerant variety, Java 56, on the right. Unfortunately, the Kavangire variety is a long-season cane and therefore not suitable for conditions in Louisiana. The possibility of breeding more early maturing varieties from these parents is being investigated.

Several of the broad-leaved varieties of cane originated at the Sugar Cane Experiment Station at Audubon Park, La., appear to be immune. Although equally exposed to the contagion, no individuals of these varieties have become affected, while practically every plant of the scores of other varieties surrounding them is diseased. They have been under observation for too short a time, however, to demonstrate that their apparent immunity is permanent.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 830

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

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EFFECT OF TEMPERATURE ON THE RESISTANCE TO WOUNDING OF CERTAIN SMALL FRUITS AND CHERRIES.[1]

By LON A. HAWKINS, *Plant Physiologist*, and CHARLES E. SANDO, *Junior Chemist*, *Office of Horticultural and Pomological Investigations.*

CONTENTS.

EXPERIMENTAL WORK.

Precooling, that is, cooling down rapidly to a refrigerating temperature either before or immediately after fruit is placed in cars for shipment, has resulted in appreciable savings in the shipment of perishable fruits.

Powell[2] has shown that the precooling of oranges rendered them less susceptible to decay. He has also shown that fruit even slightly injured is much more liable to fungous infection and decay than sound fruit.

Ramsey[3] comes to much the same conclusion as regards the shipment of red raspberries from the Puyallup Valley.

Stevens and Wilcox,[4] working with strawberries, showed that *Rhizopus nigricans* Ehrenb., which causes much of the decay of this fruit in transit, could not infect unwounded berries and that less infection occurred when the berries were properly cooled and refrigerated until they reached the market.

[1] This bulletin gives the result of a portion of the work carried on under the project "Factors Affecting the Storage Life of Fruits."

[2] Powell et al. The decay of oranges while in transit from California. U. S. Dept. Agr., Bur. Plant Indus. Bul. 123, 79 p., illus. 1908.

[3] Ramsey, H. J. Factors governing the successful shipment of red raspberries from the Puyallup Valley. U. S. Dept. Agr. Bul. 274, 37 p., illus. 1915.

[4] Stevens, Neil E., and Wilcox, R. B. Rhizopus rot of strawberries in transit. U. S. Dept. Agr. Bul. 531, 22 p. Literature cited, p. 21-22. 1917.

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Ridley[1] shows that careful picking and handling, together with the prompt and thorough cooling of strawberries, reduce losses in transit.

Stevens and Wilcox [2] in a later paper showed that picking the fruit in the cool of the day decreased the losses from decay. They also found that washing strawberries picked during the hottest part of the day resulted in less loss from leak caused by *Rhizopus nigricans* than when the fruit was shipped without washing. This was considered to be due to the fact that the berries were cooled by the evaporation of the water from the surface. These writers state that "berries picked in the early morning are cool and less likely to decay than those picked in the heat of the day."

From these investigations it is evident that uninjured fruits are not so liable to decay from fungous infection as those which are injured and that fruit cooled as soon as possible after harvesting or picked when cool is less likely to become infected.

DESCRIPTION OF THE METHOD EMPLOYED.

The present investigation was undertaken to see whether small fruits when cooled were less liable to injury than if picked or handled when they are warm. The small fruits used in the experiment were black raspberries, red raspberries, blackberries, and strawberries. Cherries were also used. Most of the fruit was obtained from Arlington Farm, but for a part of it the writers are indebted to the horticultural department of the Maryland State Agricultural College.

The resistance of the epidermis of the fruit to wounding was determined by means of an apparatus which had been used in measuring the pressure required to puncture the tissue of potatoes.[3] (Fig. 1.) This apparatus consisted of a modified Joly balance. To the lower end of the spring of this balance was attached a metal rod which passed through a short glass tube attached to the upright stand of the instrument. Hair lines on both the tube and rod made it possible to determine the point at which tension on the spring balanced a given weight. At the end of this metal rod a glass rod was attached, to which was cemented a small glass needle with rounded end. The weight of the rod and needle was, of course, within the capacity of the spring. In operating this apparatus the fruit was placed on the stand of the instrument in a suitable holder and the stand was so adjusted that the surface of the fruit was just in contact with the tip of the needle when the two hair lines coincided. The tension on

[1] Ridley, V. W. Factors in transportation of strawberries from the Ozark region. U. S. Dept. Agr., Bur. Markets Doc. 8, 10 p. 6 fig. 1918.

[2] Stevens, Neil E., and Wilcox, R. B. Further studies of the rots of strawberry fruits. U. S. Dept. Agr. Bul. 686, 14 p. 1918.

[3] Hawkins, Lon A., and Harvey, R. B. Physiological study of the parasitism of Pythium debaryanum Hesse on the potato tuber. *In* Jour. Agr. Research, v. 18, no. 5, p. 275-298. 1919.

the spring was released by means of a rack and pinion adjustment until a quick drop in the needle showed that it had penetrated the epidermis of the fruit. The reading on the scale of the instrument was then taken and the weight required to balance this tension on the spring determined. The weight of the glass rod and needle, minus the weight required to balance the tension on the spring, gives the pressure of the needle on the fruit at the time it punctures the epidermis.

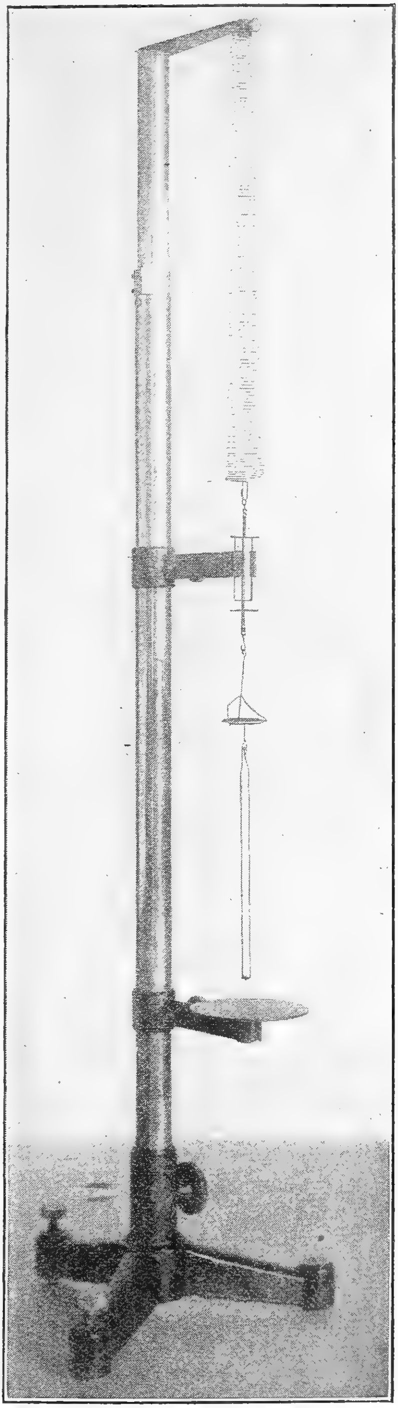

FIG. 1.—Apparatus used in determining the pressure necessary to puncture fruits.

CONDITIONS OF THE TESTS.

Five tests were made on different regions of each fruit, and a number of fruits, varying from 5 to 16, were used in all experiments. The fruit was picked in the morning of the day the determinations were made and tested at room temperature and after being cooled in the ice box. Tests were also made on berries washed in tap water, inasmuch as berries are frequently washed before packing and shipping commercially. As already mentioned, Stevens and Wilcox have shown that the washing of strawberries is beneficial. In a number of cases the fruit was tested the day it was picked, part of it placed in the ice box and tested later, and the remainder allowed to stand in the ice box for 24 hours. It was tested again on being removed from the ice box and later after it had had time to warm to room temperature. The results of these determinations with the different varieties of the fruits are given in Table I. The number of determinations indicates the number of berries or cherries used. Each berry was tested five times and the tests averaged. The pressures required to puncture the epidermis of the fruit in each separate lot were averaged, and the results are shown in the appropriate columns. The temperatures at which they were tested and the treatment given the fruits before testing are also shown in the table.

TABLE I.—*Pressure required to puncture certain fruits freshly picked and after 24 hours under stated conditions, each determination representing the average of five punctures on a single fruit.*

Variety.	Tested soon after picking.									Tested after 24 hours in ice box.					
	Warm.			Cooled in ice box.			Washed in tap water.			Warmed to room temperature.			Cold.		
	Number of determinations.	Temperature tested.	Pressure required.	Number of determinations.	Temperature tested.	Pressure required.	Number of determinations.	Temperature tested.	Pressure required.	Number of determinations.	Temperature tested.	Pressure required.	Number of determinations.	Temperature tested.	Pressure required.
Sec. A.—STRAWBERRY FRUITS, USING A NEEDLE 636 MICRONS IN DIAMETER.															
		° C.	*Gms.*		° C.	*Gms.*		° C.	*Gms.*		° C.	*Gms.*		° C.	*Gms.*
Cooney	10	26	4.41				9	26	4.76	10	25	3.64	12	16	6.34
Do	10	29	4.79	10	16	5.57	5	29	4.81						
Do	9	24	3.87	9	13	5.39							8	13	5.18
Do	26	26	4.11	18	16	6.05									
Do	7	23	5.06	5	16	6.50									
No. 29-5	7	29	4.83	7	16	7.79							7	16	6.30
Undetermined	5	30	4.95	6	16	6.79									
Do	5	23	5.28	3	13	7.07									
Sec. B.—BLACK RASPBERRY FRUITS, USING A NEEDLE 121 MICRONS IN DIAMETER.															
Undetermined	10	25	4.45	8	14	6.23				10	27	4.15	10	13	5.55
Sec. C.—RED RASPBERRY FRUITS, USING A NEEDLE 313 MICRONS IN DIAMETER.															
Ranere (*St. Regis*)	12	27	4.86	15	16	6.41				10	28	3.88	10	13	5.65
Undetermined	9	28	4.93	10	16	6.66				10	28	3.51	10	13	4.90
Sec. D.—BLACKBERRY FRUITS, USING A NEEDLE 60 MICRONS IN DIAMETER.															
Erie	15	26	5.60	16	13	6.36	15	26	5.46	12	27	5.62	15	13	7.16
Lawton	15	28	5.45	15	13	6.50	15	28	5.53	15	28	5.69	15	13	6.35
Wachusett	14	26	6.52	15	16	8.47	15	26	6.30	5	26	7.36	5	13	8.18
Lawton	14	25	5.59	15	13	6.83									
Unknown	16	26	6.00	14	13	8.11	15	26	6.24						
Do	15	26	7.92	15	12	9.06									
Erie	10	27	7.94	10	13	8.98				5	26	6.93	5	13	9.59
Sec. E.—CHERRY FRUITS, USING A NEEDLE 68 MICRONS IN DIAMETER.															
Montmorency	15	27	5.08	15	16	6.46									
Do	16	29	5.65	16	13	6.88							10	13	7.10

DISCUSSION OF RESULTS.

Table I shows that the average pressure required to puncture berries that have been cooled is considerably more than that required for warm berries. This is true not only for the freshly picked fruit but also holds for the berries that were maintained at ice-box temperature (about 16° C.) for 24 hours.

Section A of Table I shows the average pressure in grams required to puncture strawberries freshly picked and treated in various ways. With the freshly picked fruit the pressures required (with a 636-micron needle) are from 0.76 to 2.96 grams higher with the cooled berries than with fruit from the same lots tested immediately at room temperature. This is a marked increase in the resistance of the epidermis to puncture. Washing in tap water without lowering the temperature did not apparently increase the resistance of the berries to puncture, as is shown by the 14 determinations under that heading in the table. Berries maintained in the ice box for 24 hours and then tested as soon as they were removed and after they had been warmed to room temperature gave results comparable to those obtained when freshly picked berries were tested and then cooled for a few hours and tested again; that is, the pressure required to puncture the cold fruit was greater than that required for the warm fruit.

The results with black and red raspberries, shown in sections B and C of Table I, were very similar to those obtained with strawberries. With black raspberries an average of 1.2 grams more pressure was required, with a 121-micron needle, to puncture the cold berries than those at room temperature. Only one variety of black raspberries was tested. Two varieties of red raspberries were used, the Ranere (*St. Regis*) and an undetermined variety. The pressure necessary to puncture the freshly picked Ranere berries was 1.55 grams less than that required for the same lot of fruit cooled in the ice box. A 313-micron needle was used with this fruit. With the undetermined variety the difference was 1.73 grams, or practically the same as for the Ranere. Similar differences in the pressure required for puncturing these berries were observed in berries of the same lots cooled in the ice box for 24 hours and tested immediately on removal and after warming to room temperature. It was noticeable, however, that the pressures required to puncture the epidermis after the 24-hour period in the ice box were not so high as with the freshly picked fruit. It is possible that the storing of this fruit tends to make the epidermis tender and more easily ruptured.

Experiments were carried out with four varieties of blackberries, the Erie, Lawton, Wachusett, and one undetermined variety. The results of the determinations were very similar to those obtained in the work with the other berries. The average increase in pressure necessary to puncture the freshly picked cooled fruit over that required for the same lots at room temperature ranged from 0.76 to 2.11 grams with a 60-micron needle. Similar differences in the pressure required to puncture the warm and cold fruits were obtained when the fruit was allowed to remain in the ice box 24 hours. Washing the berries in tap water did not appreciably affect their resistance to puncture one way or the other. This may be due to the fact that the berries were tested immediately on removal from the water, which would preclude any appreciable cooling effect from evaporation.

The results with Montmorency cherries were practically the same as those with berries. Cooling the fruit increased its resistance to puncture.

From these results it is evident that the fruits used in the work are much less easily punctured when cool than when warm. It seems probable that this increase in the resistance of the skin to mechanical injury is an important factor in the results obtained by Ramsey, Stevens and Wilcox, and Ridley in their work on the prompt cooling and refrigeration of berries. It would seem also that the picking of berries in the early morning when they are cool, as is quite commonly practiced in some regions, would be decidedly advantageous, in spite of the fact that at that time the berries are frequently wet with dew, as no evidence was obtained that moist berries were more susceptible to injury than dry fruits.

No attempt was made to determine the reason for this increase in resistance to puncture due to cooling. A possible explanation of this phenomenon, which occurred to the writers, was that the surface of the fruit might be covered with a wax which softened at the higher temperatures but became harder and more resistant when cooled. Another purely mechanical explanation is that the walls of the drupelets or of the external cells of the fruits have a lower coefficient of expansion than their contents. If this were the case, at higher temperatures the walls would be under greater strain and would, therefore, puncture more easily. This point deserves further investigation.

In conclusion, it has been shown in this work with strawberries, blackberries, black and red raspberries, and cherries that cooling the fruit renders the epidermis more resistant to mechanical injury.

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THOMAS H. MacDONALD, Chief

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SPILLWAYS FOR RESERVOIRS AND CANALS.

By A. T. Mitchelson, *Senior Irrigation Engineer.*

CONTENTS.

SPILLWAYS.

In its ordinary use the spillway is a device for removing surplus water from a reservoir or canal, in order that the water level within the reservoir or canal may not rise above the point considered safe or fixed upon as the maximum allowable height. It is distinguished from other types of wasteways by the fact that the surplus water passes over a crest or "spills" instead of passing through openings in the dam or canal bank.

The conditions necessitating spillways are many and they vary as to the requirement for capacity, the degree of safety factor demanded, by the extent or importance of the structure they protect, the location of the spillway with relation to that of the dam or canal embankment, and the functions they must perform in maintaining a more or less perfect control of the reservoir or canal in times of maximum inflow when a predetermined flowage line or freeboard must not be exceeded. This necessitates the provision for passing the highest floods over the spillway within the safe limit of maximum rise, and the conveyance of this water away without injury to the dam or canal embankments or to their appurtenant structures.

If a reservoir is to be located in a stream channel where the extent of inflow is not under human control, the spillway must provide for the passage of both normal and flood flow when the reservoir is full

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and must protect the dam or embankment from being topped if it has not sufficient structural resistance to withstand the resultant shock, pressure, and vibration imposed upon it by overflow of considerable depth. In the case of earth dams or embankments it is necessary to provide a means for conveying the falling water away from the point where the embankment strikes the surface below it.

An elaborate method resorted to in accomplishing this purpose is shown in figures 1 and 2, Plate I, illustrating a system of drops and a stilling pool at the foot of the Lahontan Dam in Nevada. In any case it is necessary to provide a means of neutralizing the energy developed in the fall of the water over the dam at the point where it strikes the stream below so as not to endanger the structure by undermining it.

When the reservoir is not in the stream channel the conditions under which the spillway is to operate are greatly simplified in that the flow of the water is generally regulated either by diversion of all or part of the stream flow into a channel and thence to the place of application or storage (see fig. 1, Pl. II); or it may be supplied by long conduits always controlled by some system of headworks. Under such conditions, when it is necessary to provide spillways, they are designed to pass such excess of water as may reach the reservoir by the failure of the inlet works to function properly, the accumulation of surface water due to superdrainage, or a combination of the two.

Examples of spillways where there is regulated flow into the reservoir are numerous, and figures 1 and 2, Plate III, show a provision for an earthen dam in Mockingbird Canyon near Riverside, Calif., and the East Park Reservoir Dam of the Orland Project, near Orland, Calif., where there is a separate spillway and, in addition, a diversion dam and inflow control. The Roosevelt Dam shown in figure 2, Plate II, is an example of the type where the spillway is provided either in a center section or at the end, and provision made for the impact of the falling water where it strikes the stream below. The Holter Dam of the Montana Power Co., near Helena, Mont., a cross-section of which is shown in figure 4, is an example of an "ogee" type of dam provided with baffles and a water cushion to dissipate the energy developed in the overpour.

With relation to spillways in connection with canals, the same general characteristics prevail and their discussion may be taken up along the same lines though more properly following the cases where the inflow is regulated. In discussion of canals, spillways and escapes are generally included in the same class of structures, called wasteways, and although they are both used as protective agencies in the canal system, they differ somewhat in their functions. They properly should be divided into two classes in that an overflow spillway is used to discharge the waters from a canal when it becomes filled beyond its normal capacity. When thus used the structure is essentially automatic in action and serves as a safety valve to prevent the canal from being overloaded and consequently overflowing its banks with disastrous results.

The escape can be either a spillway, a wasteway, or a sluice gate, the last named differing from the spillway of the overflow type in that it can be used for partially or completely emptying a canal. It is seldom automatic in action and requires some means of rapid operation, since it is usually required to operate immediately in case of a break in the canal banks below it. Only local conditions can suggest the advisability of locating one of these structures on a canal system or determine whether or not it is necessary, but the protection it affords the canal and its appurtenant structures usually warrants the cost. The number and distance apart at which wasteways should be located are dependent upon the importance of the canal, the topography of the ground above and below the canal, and the character of the service the structure itself is to perform.

A spillway acts automatically and operates to prevent a rise in the canal level beyond a safe freeboard. This rise may be the result of an excess of water coming from the headgates, surface run-off from lands higher than the canal, an excess flow produced by the closure of lateral gates above the structure, or by an obstruction falling into the canal, or the closing of an outlet or checkgate below the escape. A spillway must be designed to take care of the most adverse conditions resulting from these causes and in its design there must be considered the maximum quantity of water the structure will be required to discharge and the maximum rise above normal water surface which the canal will stand. These factors are often assumed and are rarely absolutely reliable.

The escape or spillway may include a checkgate as a part of the structure, in which case it must not only be capable of undertaking the duties of an overflow spillway, but those of an escape as well where the full capacity of the canal must be discharged. Ordinarily, however, the principal function of an overflow spillway is to discharge the surplus water above the desired normal canal capacity, whereas an escape is intended to spill the entire flow of the canal if necessary. An escape, on the other hand, embodies both types, but is intended for the protection of the system below it and to divert the entire flow of the canal to some natural drainage channel in case of a break or other emergency. It also may be used as a scouring or sluice gate, ridding the canal of deposited silt. The functions of the three may be obtained by building the structure in combination with a check immediately attached or a short distance below the spillway, escape, or sluiceway, as the case may be. Provision must be made to discharge any excess over the safe capacity of the canal in countries where heavy rainfall occurs periodically, or where melting snow may affect surface run-off from the higher lands draining into the canal during the operating season. It may be desirable to collect part or all of such drainage and carry it as additional storage. Escape structures should also be provided with means for taking care of any surplus water in the canal produced by regulation of the flow in one part of the canal system without having provided for changes in all other parts of it. Their location will be desirable above points of questionable strength, above stretches of canal located on steep sidehill where slides are apt to occur, just above the intake of any important structure where there is any danger of erosion around its intake, or above any structure whose direct loss would not be material compared to the resulting damage to valuable property either connected with or foreign to the canal system. Capacity should be computed from the possibilities of combined flows resulting from conditions apt to develop above the structure.

The overflow spillway, wasteway, and sluiceway are similar in the common characteristic of requiring the addition of a wasteway channel to divert the waste water to a point away from the vicinity of the canal.

There are two general types of spillways, overflow spillways, and siphon spillways. The distinguishing features of the two types are that the capacity of the overflow spillway depends upon the length of the crest and the height of the water above the crest, and is increased in no way by the distance through which the water falls below the crest; while the capacity of the siphon spillway depends upon the area of the cross-section at the smallest part of the siphon and the difference in elevation of the water surface at the intake and outlet ends. In other words, the siphon utilizes the fall from the water surface in the reservoir or canal to the discharge end of the siphon to increase capacity, while the overflow spillway makes no use of most of this fall. The two types of spillways are discussed in detail, as follows:

OVERFLOW SPILLWAYS.

Overflow spillways are of three general types, the "ogee," the "steps," and the simple inclined type. Some dams combine the first two of these types by utilizing the top part as an ogee and having the lower portion stepped to break the velocity of the falling water.

Flow over a spillway is produced by the velocity resulting from the head measured from its crest to the surface of the water in the pond above. It depends entirely upon the stored head to increase volume per unit length, and, regardless of the height of the crest above the pool into which the water is spilled, no part of the fall below the crest level is effective either directly or indirectly. In

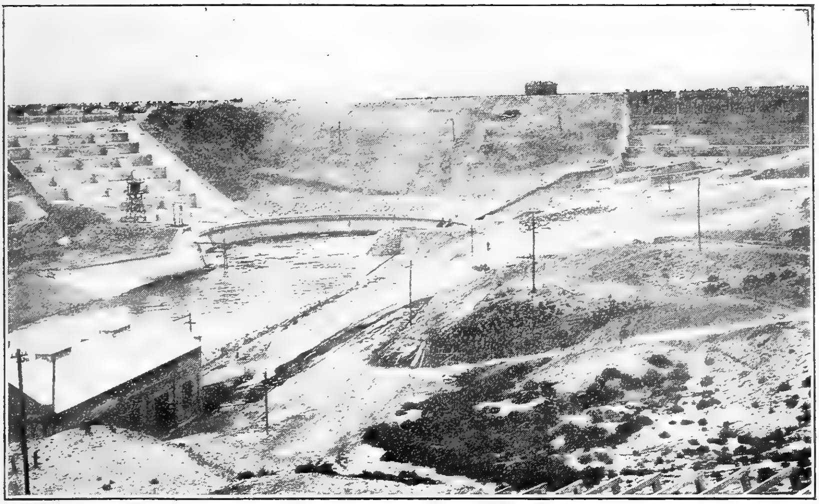

FIG. 1.—SPILLWAY OF LAHONTAN DAM, NEVADA.

Looking upstream and across stilling basin which receives the combined waters of the converging spillways.

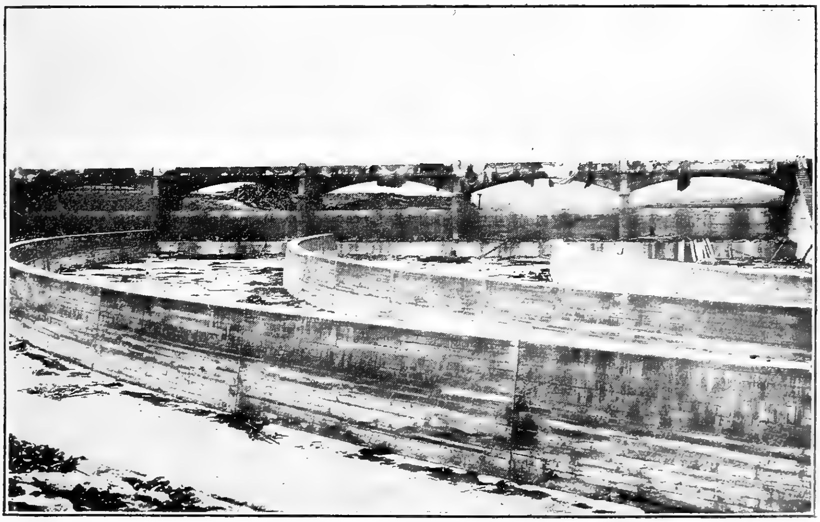

FIG. 2.—LAHONTAN RESERVOIR SPILLWAY, NEVADA.

Looking upstream and across the upper end of right-hand spillway. Shows training walls

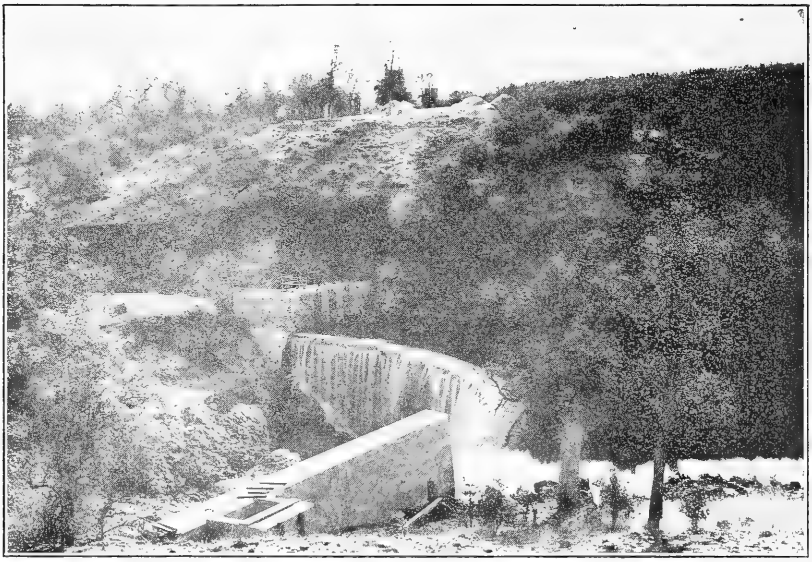

FIG. 1.—HEADWORKS, EAST PARK SUPPLY CANAL, ORLAND PROJECT, CALIFORNIA.

Shows diversion of part of waters of Big Stoney Creek into East Park Reservoir. Note gate control of supply.

FIG. 2.—ROOSEVELT DAM, ARIZONA.

The two overflow spillways are shown at each end of the dam. Water for irrigation is discharged through the tunnel shown on the left and through the turbines of the power plant shown in right center.

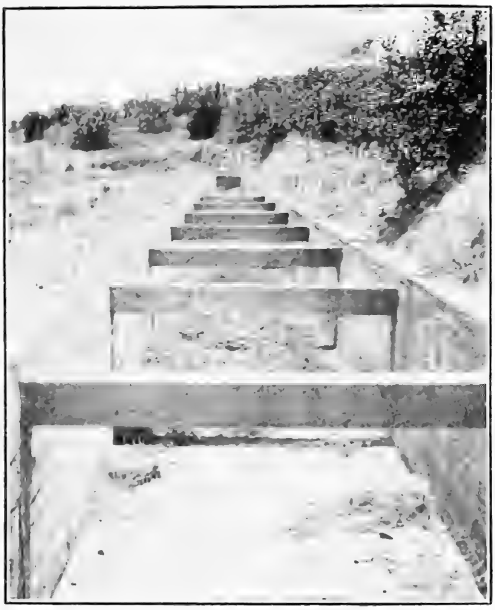

FIG. 1.—SPILLWAY OF EARTH DAM, MOCKING-BIRD RESERVOIR, GAGE CANAL CO., NEAR RIVERSIDE, CALIF.

Spillway crest is left edge of channel shown in cut.

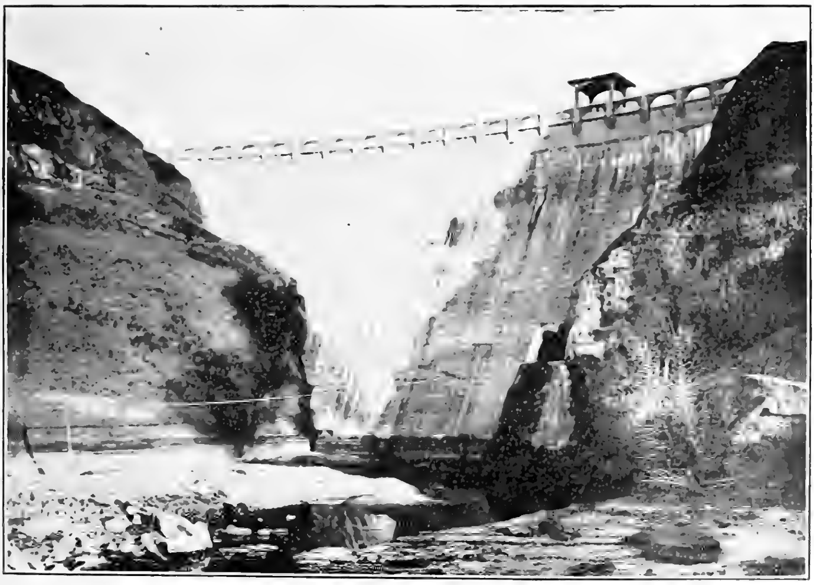

FIG. 2.—EAST PARK DAM, ORLAND PROJECT, CALIFORNIA.

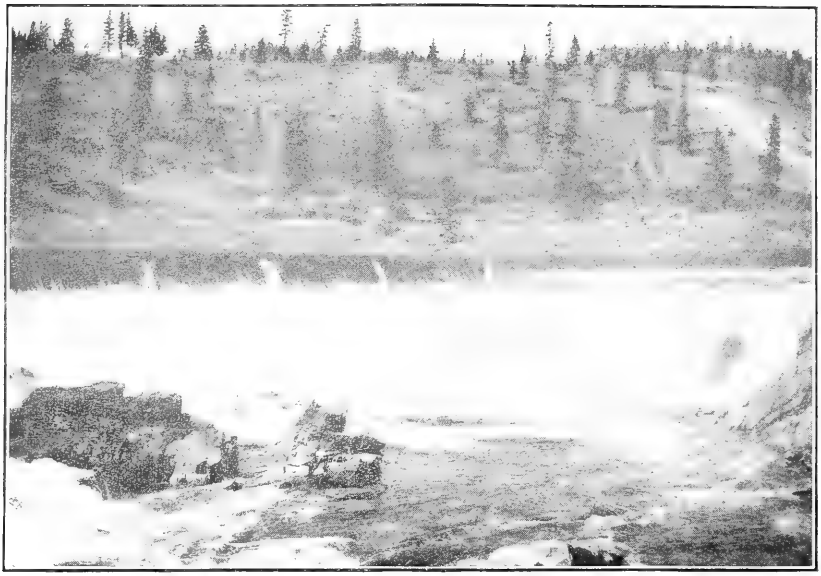

FIG. 1.—DIVERSION DAM, WASHINGTON POWER CO., NEAR SPOKANE, WASH.
Built at the Little Falls plant in the form of an "L" to gain crest length

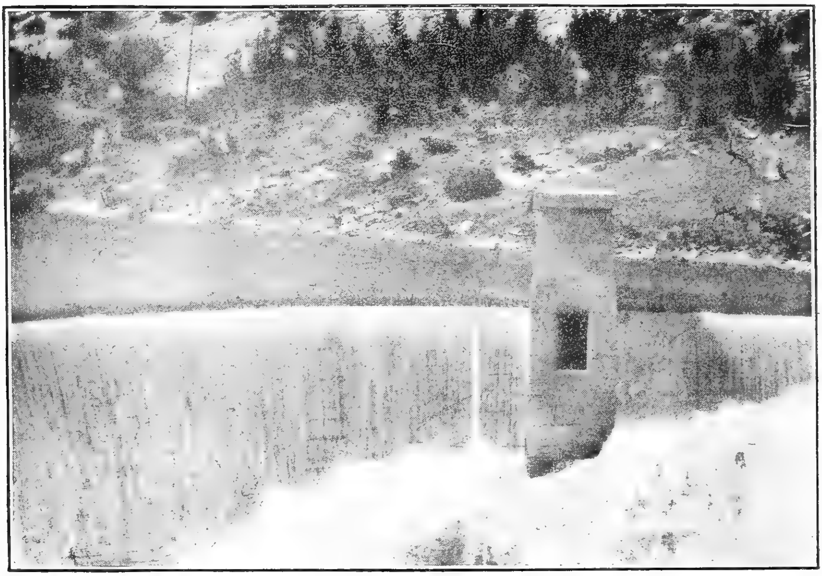

FIG. 2.—ARCHED TYPE SPILLWAY DAM, PISHKUN RESERVOIR, MONTANA.
Air intake tower shown in center of picture built to eliminate vibration due to vacuum.

other words, if a dam were 30 feet higher than the surface of the tail water at its base, and there were 5 feet of water pouring over its crest, of the 35 feet available head only 5 feet, or about 14 per cent, would be utilized to produce velocity. Since the two principal factors determining capacity are length of crest and head and the allowable increase in head is small, the only available means for increasing discharge is by increasing the length. One of these factors directly governs the other and only by knowing one of them definitely can the other be determined; or if the discharge of the stream is known and the head allowable as a depth of overflow is definitely fixed, the length of spillway to provide a specified discharge can be computed from the standard wier formulas by selecting the proper coefficient for the form of weir crest under consideration. These formulas and their corresponding coefficients are very indefinite because of the fact that they have never been proven to be accurate for heads of more than 4 or 5 feet over the crest of the weir.

Furthermore, in determining the required capacity of the spillway, a careful study must be made of the record or data relating to the precipitation or run-off of the catchment basin it is destined to serve and a liberal factor of safety added to the results of the computations to insure security in case of discharge greatly in excess of any known flood record, and in spite of the retentive capacity of the reservoir.

Long crests discharging thin sheets of water will give greater factors of safety than short spillways with greater depths, will afford less liability to fracture or do other damage to the dam as a result of the impact of the heavier volume of water, and will insure closer regulation of the pond level.

In the common formulas applied to determine spillway capacity, there are different elements to be considered in their application to the case under consideration, such as height of crest above the bed of the reservoir or canal upstream from the crest, length and width of crest, velocity of approach, correct determination of the head on the crest, and the number of end contractions, if any. All these influence the efficiency of the structure as a whole.

Possibly the formula most used in the United States is the Francis formula expressed in its simplest form as $Q = CLH^{\frac{3}{2}}$, and which is modified by the introduction of the elements referred to above whereever they apply. For instance, with velocity of approach this formula would be changed to read

$$Q = CL[(H+h)^{\frac{3}{2}} - h^{\frac{3}{2}}]$$

and if it considers velocity of approach and end contractions it must still be modified to read

$$Q = C(L - 0.2H)\,[(H+h)^{\frac{3}{2}} - h^{\frac{3}{2}}].$$

The Bazin formula is more complicated and may be expressed as,

$$Q=\left(0.405+\frac{0.0984}{H}\right)\left(1+0.55\frac{H^2}{(p+H)^2}\right)LH\sqrt{2gH}.$$

The constant C is dependent not only upon the width of the crest, but also upon its shape. The data resulting from the experiments to determine this factor are not consistent even for the same form of weir crest, but vary according to the head. They do, however, form a basis for the approximation of discharge over any form of weir under conditions ordinarily encountered.

As has been stated, the experimental data from which discharges are to be computed include heads of only from 4 to 6 feet, whereas flow over spillways varies from 0 to 14 feet deep. The effect of form of crest and friction decreases as the head increases, and it is also probably true that the coefficient for many ordinary forms of weir sections would tend toward a common constant value if the heads were indefinitely increased. This would be due to the more definite form of the "nappe" resulting. It is assumed also that flow over the spillway may be affected by the form of the nappe, which in turn varies when it discharges freely, merely touching the upstream crest edge, adheres to the downstream face of the crest, adheres to the top of the crest, adheres to both top and downstream face, remains detached but becomes wetted underneath, adheres to top, but remains detached from face and becomes wetted underneath; or it may be replaced by a depressed nappe having air imprisoned underneath at less than atmospheric pressure. A method of eliminating the effects of the last condition is shown in figure 2, Plate IV. Experiments have been conducted to determine the influence of the various conditions, and its extent, under heads of from 0 to 5 feet and over different forms of model dams, with crests ranging from a sharp edge to a width of 16 feet. Tables have been published giving the results of these experiments and coefficients for almost any form of weir crest to be applied for discharge computations of spillways under the various conditions.[1]

So much depends upon the judgment of the person making the assumptions, which in turn become fixed factors in the computations, that there very often appears the greatest difference in the resulting dimensions. The writer has had a case called to his attention where three engineers computing the dimensions of a dam as a suitable design for a certain location, and starting with the same assumed discharge, varied as much as 14 per cent in the discharge for a given crest length and head in a maximum discharge of approximately 100,000 second feet.

[1] The information concerning these tables and the discussion relative to weir discharge are based on the writer's personal opinion, resulting from a review of U. S. Geol. Survey Bul. 200, "Weir Experiments, Coefficients, and Formulas," by Robert E. Horton.

This is not surprising when it is seen that only one of the factors entering into the formulas cited is fixed by the form of the structure. It has been stated that in the process of gaging streams at dams the head is usually measured in comparatively still water in an open pond, but this is an assumption at best and must be corrected to conform to an assumed velocity of approach. In this connection it may be well to mention that the more complicated Bazin formula quoted in another part of this paper includes the correction for velocity of approach in the weir coefficient, and therefore the coefficient for a given weir is comparable only with the coefficient of another weir under the same head when the velocity of approach is the same in both cases. The Bazin formula also expresses the velocity of approach by means of the depth and breadth of the leading channel, which is rarely if ever of regular form so that the use of such an unreliable base is questionable. It is not the intention to discuss in this paper the relative values of the different formulas with their corresponding exponents and coefficients to apply in the various cases, but it is attempted to point out the great number of factors to be considered in the design of a spillway to keep the pond level within limiting bounds and at the same time perform its duty as a safety valve in times of excessive stream discharge. The uncertainty arising from the use of these formulas and the assumption of the maximum quantity of water to be discharged emphasize the need of using a liberal factor of safety in the protection of that part of the structure to be guarded. At best the result is merely an approximation.

Overflow spillways seldom are fully satisfactory on a canal system, since their crests are ordinarily built parallel to the center line of the canal, and to produce the effect of a normal canal supply the depth of water in the spillway over the lip would have to range from the maximum depth above normal surface in the canal at the upper end of the spillway to no depth at all at the lower end. Otherwise the canal would still be above normal supply beyond and below the spillway, and to produce full efficiency the crest of the spillway would have to be abnormally long. The writer has observed that the depth on the crest of most canal spillways is practically the same at both ends unless a long crest is built, which adds greatly to the cost. The use of an abnormally long spillway on a canal to discharge the water in excess of the normal supply, or above important structures where overflow would be particularly serious, requires the addition of costly and extensive training works and channels to divert and convey the wasted water to some natural drainage channel. Economy has been approached in some cases by the construction of the upper portion of these conveying channels parallel to the center line of the canal or spillway, or by building the spillways in a dentated form to gain crest length and at the same time reduce the area of the wasteway channel at its upper end. One of these methods is shown in figure 1, Plate V, and another in figure 2, Plate V, and in cross-section in text-figure 1. The manipulation of the latter is described.

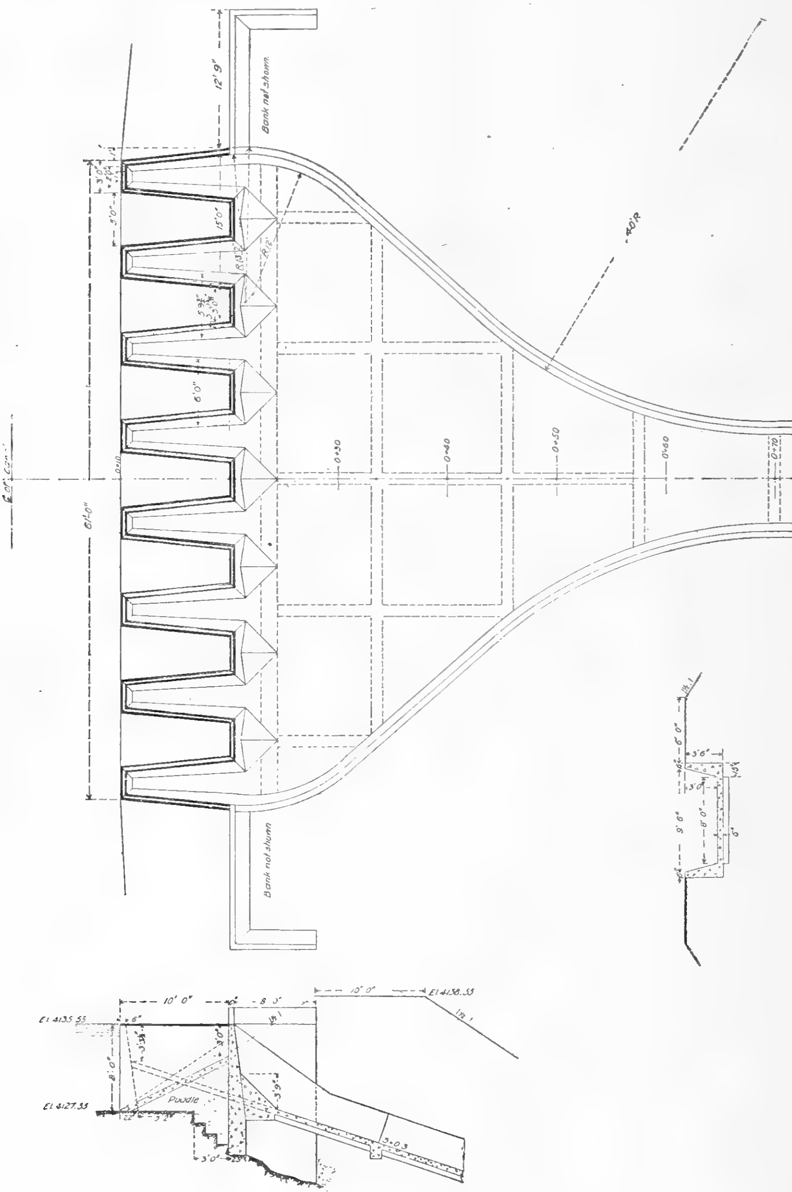

Fig. 1.—Spillway with concentrated crest length, Klamath project, Oregon. Built in dentated form to control flow line of Keno Canal where conditions would not permit of straight crest.

A spillway of reinforced concrete with a concentrated crest length designed to divert 600 second-feet of water from the Keno Canal of the Klamath project of the United States Reclamation Service has been built at Klamath Falls, Oreg. (fig. 1). The water spilled is diverted to the Link River after it has been used to generate power. The fall from the canal to the river is 48 feet in a distance of about 170 feet. The canal would not permit of a rise greater than 1 foot above flow line, because it was built along a steep side hill and it was impractical to construct the banks of sufficient height to allow of any considerable rise. The conditions required a structure capable of spilling the waste water resulting from the proper regulation of a power plant above the structure without at the same time causing an excessive rise in the canal flow line. The sudden closing down of the entire plant presented an emergency in which the entire flow had to be taken care of quickly without exceeding the limiting rise and fall of flow line. An overflow spillway crest to satisfy such demands with its safe coefficient of discharge was calculated to be about 200 feet long, and to utilize as small a horizontal distance as possible was concentrated by indentations to a length of 61 feet as measured in a straight line along the canal bank.

The principal reason for concentrating the over-all length of the spillway was to provide a wasteway channel through which the water would be conducted over the earthen slope to the river after flowing over the crest. A section 3 by 8 feet with the slope of the ground at the point was capable of taking care of the discharge after it had been collected, but the concentration of crest length was to reduce, as far as possible, the dimensions of the upper portion of the collecting channel and therefore the cost.[1] The structure only resulted in this saving, as the same length of spillway had to be provided with consequent cost of construction. It is another example of the adaptability of the siphon spillway in cases where space and close regulation are paramount.

SPILLWAY CONTROL.

It may be desirable normally to carry the water near the maximum allowable level rather than sufficiently below that to provide for emergency flow. This is provided for by placing the permanent crest of the spillway sufficiently low to pass the maximum flow, and placing on top of this temporary or movable parts which will go out automatically or can be removed or adjusted in case of flood so as not to interfere with floating débris. The immediate removal of these barriers is of particular importance, because having provided an ample spillway it should be kept free of any obstruction and at all times ready for any sudden demands made upon it, regardless of other agencies which may be provided as additional facilities in effecting discharge. Inadequate satisfaction of these conditions has led to a great number of wrecked structures resulting in the loss of

[1] Description from an article in Engineering News, Sept. 9, 1909.

life and property. Sometimes legal requirements fix the flow line or it may be desirable to maintain a constant head in the reservoir. Long crests to keep the rise of the pond level within a minimum limit have been built and where the site did not permit of a straight-line crest, modification of the form has been made as in the case of the East Park reservoir of the Orland project, where crest length was gained by forming it in a series of nine semicircular arches resting against piers 8 feet wide. The arches have a radius of 13.5 feet and the whole structure is curved to a radius of 474 feet, the total length of spillway crest being 460 feet. It was designed to care for a discharge of 10,000 second-feet with a depth of 3.7 feet of water

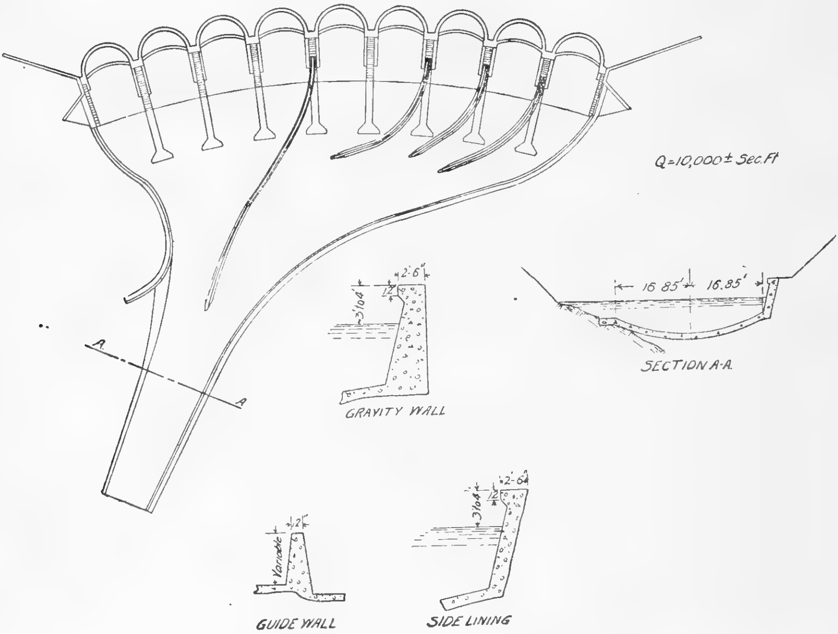

FIG. 2.—Plan and cross section of East Park reservoir spillway, Orland project, California. Form of dentated type of spillway composed of a series of nine piers, each 8 feet wide.

flowing over the crest. The spillway is located in a saddle about one mile from the dam and its outline is shown in figure 1, Plate VI, and in text-figure 2.

The Little Falls dam of the Washington Power Co., near Spokane, where the crest was built in the form of the letter "L" is shown in figure 1, Plate IV. The accomplishment of the above results, however, will add greatly to the cost of the structure if the longer crest has to be provided by the lengthening of the dam.

When acceleration is due to a shorter crest length and a resulting increase in the head to effect discharge, the devices serving to produce a regulated pond level must be under direct control. The addition of such devices invariably serves the primary purpose of the spillway in facilitating the escape of the increased inflow, but lacks the automatic character which must be the distinctive feature of the true spillway. These agencies may be (1) flashboards in their various forms; (2) sliding gates or sluiceways; (3) Taintor or radial gates; (4) tilting or counterweighted gates; and (5) rolling dams or barriers. These are discussed in the order listed.

FLASHBOARDS.

Flashboards are the simplest but most unsatisfactory device. They permit of fairly close regulation of head due to the possibility of setting them to any desired width. The boards may be placed between stationary piers or may be held in place by tilting arms or braces set in line on the crest of the spillway so that they may not retard flow during flood, but will afford a certain pondage to provide surplus water from the time of minimum to that of maximum demand. This is shown in figure 1, Plate VII.

Another method is to have holes in the crest of the dam or spillway into which iron pins of a certain size and predetermined fiber stress per unit area are set and the boards fastened to these pins by staples. (Fig. 2, Plate VII.) The pins are calculated to resist pressure of the flashboards set against them up to a certain point, and when they bend the boards are released and go down the stream.

Such practice is not economical and is uncertain, due to the great variation in the strength of the iron pins. Where the storage of flood water is essential or desirable and the stored water is very valuable, this use of flashboards is not recommended, because they are generally leaky, and when they have gone out they can not be replaced until the freshet or flood has passed, making it impossible to store any of the flood water.

Flashboards are also installed as a permanent part of the spillway and are lowered automatically at different stages of water level, as are other devices hereafter discussed. The use of flashboards under any plan in which they must be removed one at a time is dangerous, because of the length of time it takes to remove them, since sudden floods might result in damage to the works before the boards can be removed.

SLIDING GATES.

Sliding gates are not adapted to use as emergency escapes for flood water, since they are not automatic in action, although ordinarily they are provided with mechanical means for quick operation. Ordinary slide gates are the slowest of all the types of gates to operate and are not suitable because of the destructive effects of vibration due to high velocity, and are extremely costly when placed in a structure on a large scale to quickly discharge large volumes of water. The cost of installation and operation is a large factor in discouraging their use. They are useful as a means of entirely emptying a reservoir in case of accident or to scour out silt when they are placed low for these purposes, and they should be provided only as an additional safeguard and not when the passage of flood water in excess of the safe flow is required. Examples of outlet gates and the elaborate towers necessary for their installation are shown in figures 1, 2, and 3, Plate VIII.

TAINTOR OR RADIAL GATES.

Taintor or radial gates are usually set between piers as buttresses and on the crest of a spillway to provide additional storage. They can be operated with the expenditure of less power and time than the other types of gates. They have cylindrical surfaces and are so connected as to revolve on an axle usually connected to the curved face by means of arms or braces, the axle being set parallel to the center line of the crest on which the gate is mounted.

Two examples of radial gates are shown in figures 1 and 2, Plate IX. The curved or cylindrical surface may be of wood, steel, or reinforced concrete. Where radial gates are mounted to pass drift over the crest of the spillway in large openings and there is danger of the axle catching débris and clogging the passage, the long axle is eliminated and in its place bearing tubes are placed in the sides of the piers, and into these pins are set to form pivots or hinges. The radial arms of the gates are connected to these pins, so that the only forces to be overcome to lift them are the weight of the gates and the friction on the pins or pivots and on the faces of the buttresses or piers, because the pressure has been, of course, transmitted to a single point instead of being distributed over an extended bearing face, as in the case of the ordinary sliding gate.

The main objection to the use of the radial gate is that it lacks automatic control, unless its specifications of installation more properly conform to the class following, and the fact that it is seldom watertight where it comes in contact with the crest of the spillway or the sides of the opening.

TILTING OR COUNTERWEIGHTED GATES.

Tilting or counterweighted gates are among the number of ingenious types of automatic gates which have been designed and installed on spillway structures in this country and in Europe where it is necessary or desirable to maintain a relatively constant head under fluctuations, floods, or changeable use of water. Three types of these are shown in figures 1 and 2, Plate X, and in text-figure 3.

They are usually patented, vary in form of construction and in method of operation, and are satisfactory only to a certain extent.

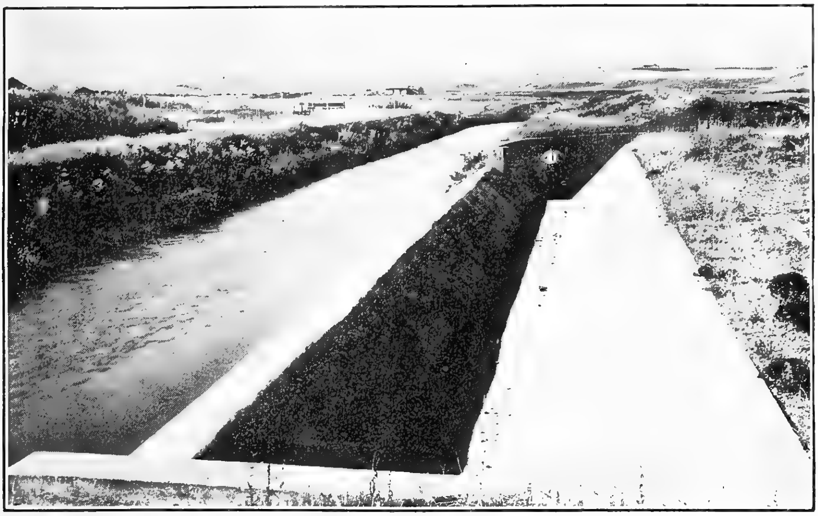

FIG. 1.—SAFETY WASTEWAY—LOWER YELLOWSTONE PROJECT, MONTANA.

Shows long overflow spillway on canal with upper end of wasteway channel parallel to center line of canal and crest of spillway.

FIG. 2.—SPILLWAY WITH CONCENTRATED CREST LENGTH, KLAMATH PROJECT, OREGON.

This cut shows the details of the structure, and it also shows the high-water line on the upper bank of the canal.

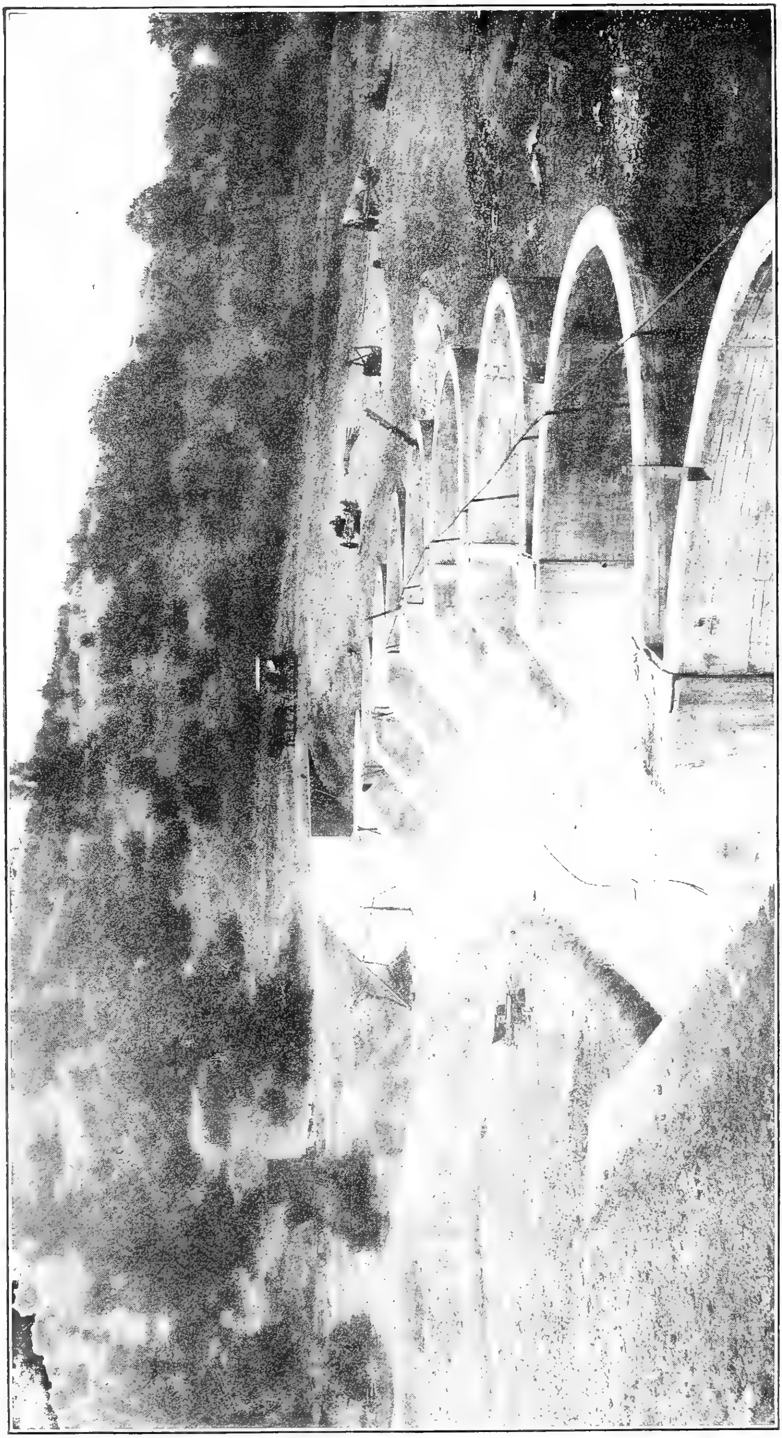

FIG. 1.—EAST PARK RESERVOIR SPILLWAY, ORLAND PROJECT, CALIFORNIA.

Shows view of spillway before curved training walls and wasteway channels were added to structure. This is one form of dentated weir intended to provide additional crest length.

They are installed as regulatory devices on numerous canal systems, where they work perfectly, because in such capacity they are kept in working condition by more or less frequent use of the operating parts. On spillway crests, where they have a limiting range of possibilities and their operation is less frequent, tending to make them less sensitive to the reaction of theoretically determined pressures, they are not as serviceable, unless the mechanical equipment necessary to operate them is more complicated and correspondingly costly. The moving parts must be maintained in the same perfect condition as that upon which their design was based if they are to function as they are intended, and such ideal conditions are rarely approached in actual spillway operation. Most types depend upon some system of counterweights to effect adjustment after they have been tilted by the action of the water pressure beyond a certain point. Or they may be so arranged that the water pressure on the gate or flashboard will cause them to react upon a cylindrical weight in such a manner as to make it ascend an incline by means of energy transmitted to the ends of the cylinder through ropes or cables; or others are arranged so that the tilting of the gate transmits power to the shaft from which counterweights are hung, such transmission being through chains or cables. Various methods are provided by which the introduction of cams or eccentric gearing may result in the compensation of the accelerated movement which might cause the slamming down of the gates or their too rapid rise.

An automatic form of spillway or floodgate has been installed on the Cedar River, near Nashua, Iowa. The design is one of the many patented types, but seems to be of simple operation. Figure 3 in section shows an outline of the structure, which is mounted on the top of a masonry dam 17 feet high and used for the generation of electric power. Each panel of the gate is 46 feet long and is so set that it will store 7 feet of water above the crest of the dam. To one end of a walking beam there is attached a reinforced concrete counterweight and a bar connects the other end with the floodgates. The gate is hinged at the bottom so that when the water rises above a predetermined elevation the gate is forced down and the counterweight is raised. As the height of water increases the pressure still further lowers the gate. When the gate opens the leverage between the counterweight and fulcrum increases, while it decreases between the fulcrum and gate hinges, and in this way overcomes the increased weight of water at every stage of gate opening.[1]

ROLLING DAMS OR BARRIERS.

Rolling dams or barriers have had their term of popularity and a number of them were installed on dams in this country. Possibly

[1] Description from Engineering News-Record, Aug. 9, 1917.

more of these have been installed on the more recently constructed spillway regulators than any of the other devices. Their popularity is based on the possibility of using them where long span is essential. The rolling dam is a patented type and consists of a large hollow cylinder, the diameter of which is usually made to correspond to the height to which it is desired to raise the pond level above the crest upon which the cylinder rests. Its length is made equal to the width

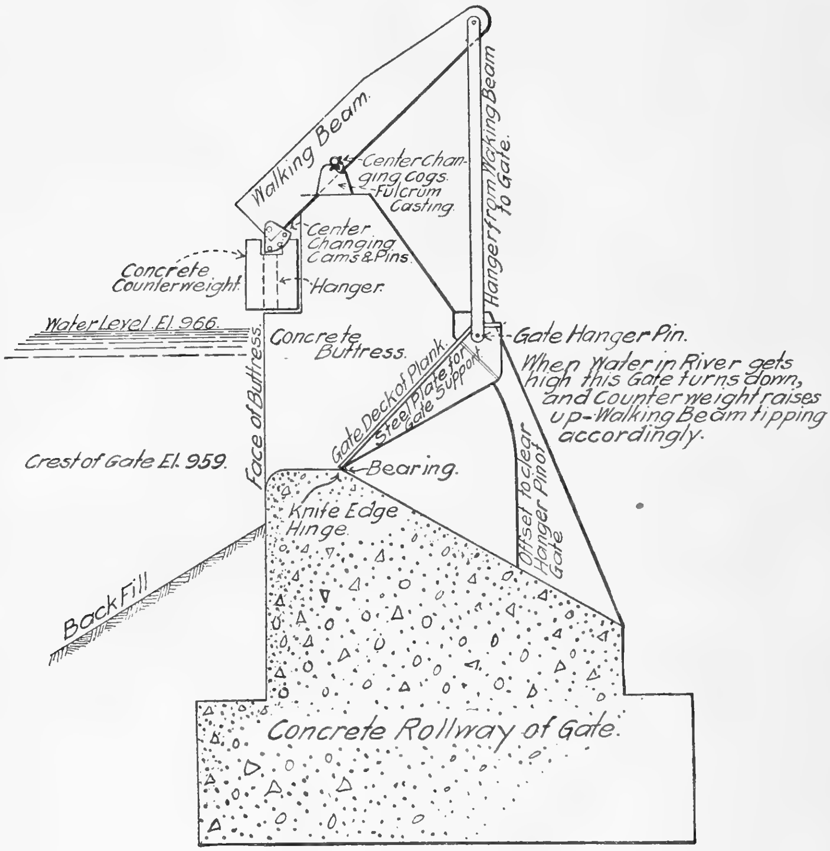

FIG. 3.—Concrete dam 17 feet high with flood gates, Nashua, Iowa. This structure on the Cedar River is equipped with automatic flood gates 7 feet high by 46 feet long.

of the opening into which it is fitted. As a general thing the material of which it is made is boiler plate riveted together and braced to withstand the strain to which the dam is to be subjected. The mechanical operation is provided for by having a gear engage a rack on an inclined abutment and by means of a sprocket chain wrapped around one end of the cylinder and connecting with the operating mechanism, the dam is rolled up or down the abutment as desired. The power is generally furnished by an electric motor or by winches. Various forms have been installed at Grand Junction, Colo., on one of the spillways of the United States Reclamation Service at Boise, Idaho, and on numerous other spillway crests in this country and in Europe.

On the Grand River, near Grand Junction, Colo., the spillway of the United States Reclamation Service is provided with seven such rollers, six of which are 70 feet long and 10.5 feet high, and one 60 feet long and 15.33 feet high. They are set on the crest of a concrete spillway of the ogee type, 24 feet high and 537 feet long as measured between abutments, the spillway being designed to care for a discharge of 50,000 second-feet.

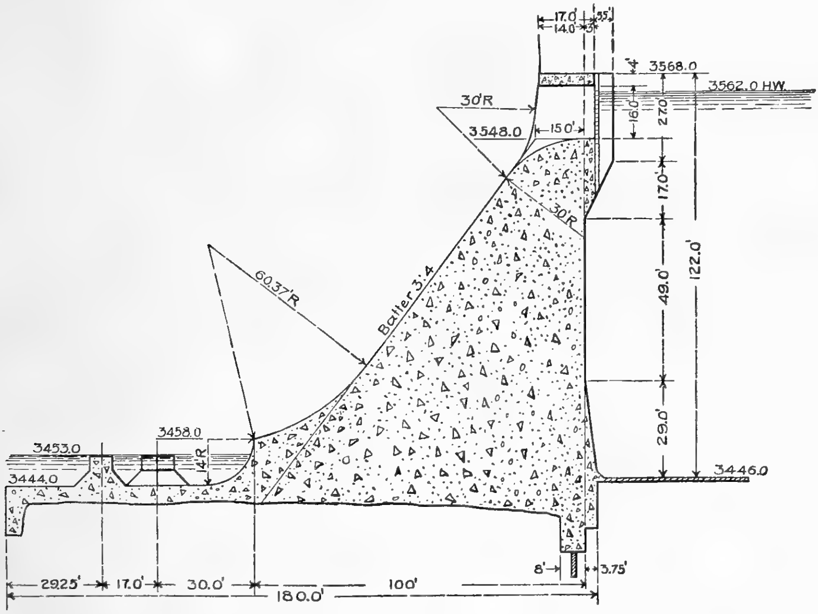

FIG. 4.—Holter dam of the Montana Power Co. Cross section of spillway of development near Helena, Mont. Shows baffles at toe of dam to neutralize the energy developed by the water pouring over the crest.

All these devices, as stated, are for spillway control and add nothing to its capacity or to its value as an automatic structure other than to lower the crest in times of flood and permit of raising the water level in normal times.

SIPHON SPILLWAYS.

As long ago as 1870 siphon spillways were used in Europe, but their operation required an ejector to cause them to function properly. Later designs making them as nearly automatic as construction conditions permitted were perfected and installed at about the same time by Heyn in Prussia, and Gregotti in Italy.[1]

[1] Engineering News, Apr. 20, 1911.

These were of comparatively small dimensions, however, and of a rather low degree of efficiency—estimated at from 40 to 50 per cent. A higher state of development was later obtained in France, where reinforced concrete was used and more efficient functioning effected by proper proportioning of the essential parts of the structure. Fear of the possibility of freezing weather interfering with the operation of the siphon spillways is said to be the principal reason why American engineers failed to adopt this type of structure, but a modification of the design led to the overcoming of this difficulty and to their rapid adoption at a number of points throughout the United States. The lowering of the intake leg well below the normal water surface, and the draining of the outlet sealing basin to prevent the possibility of clogging at that point, did away with the ice menace and also prevented the possibility of débris collecting or lodging in the throat.

There should be little argument against the use of the siphon spillway on canals or in connection with reservoirs where absolutely automatic control without the maintenance of mechanically operated devices is desired, and where there must be close regulation of the rise and fall of the water surface. Economy of cost, space, and rapidity of control greatly argue in favor of such structures, especially where laws require close regulation of the pond level, as in Italy where 8 inches is the limiting range. It is also most efficient where immediate response to sudden rises in water level is essential, because of the fact that it is brought into action to its full capacity with the rise of only a few inches, whereas the overfall spillway is not fully effective until the danger point is reached and then is dependent upon the stored head for acceleration of velocity.

The use in this country of siphons as spillways is much more recent than it is in Europe, some of the earliest examples being constructed in 1910 on the New York State barge canal.[1] Since then they have been used on the fore bay of a hydroelectric plant of the Tennessee Power Co. and on the power canal of the Mount Whitney Power & Electric Co. in California. They have been used still more recently on several projects of the United States Reclamation Service and on a number of irrigation and power projects in California, the notable cases being the Orland, Salt River, Yuma, and Sun River projects of the Reclamation Service; the South San Joaquin Irrigation District; the Sweetwater Dam near San Diego; and the Southern California Edison Co. at Huntington Lake, Calif.

As has been shown, the head utilized to produce flow in an overflow spillway is figured from the surface of the water above the spillway to its crest, although the actual head available, but which is not utilized, is much larger, being the total head from water surface

[1] Engineering Record, July 30, 1910, and Oct. 8, 1910. Eng. News, Nov. 17, 1910.

FIG. 1.—SOUTH OVERFLOW SPILLWAY, SWEETWATER DAM, CALIFORNIA.
Showing inclined braces along top of spillway crest to support flashboards.

FIG. 2.—SPILLWAY OF DIVERSION DAM NEAR WOODLAND, CALIF.
Showing holes along center line of crest to receive flashboard pins.

FIG. 1.—GATE TOWER, MAMMOTH RESERVOIR, UTAH.

This dam was washed out in the spring of 1917 because of inadequate spillway.

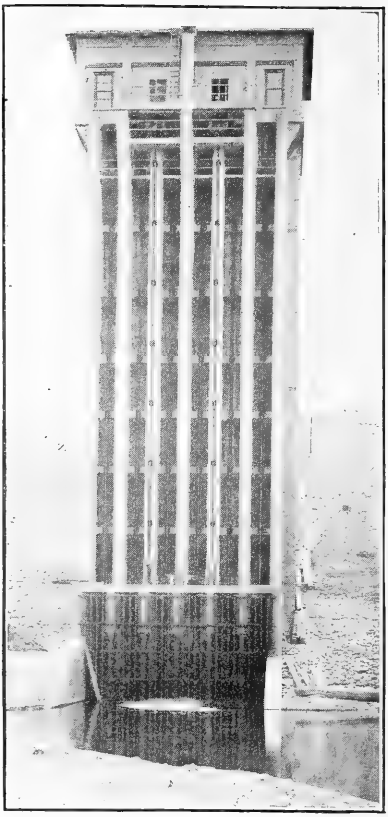

FIG. 2.—OUTLET GATES AND TOWER, LAHONTAN RESERVOIR, NEVADA.

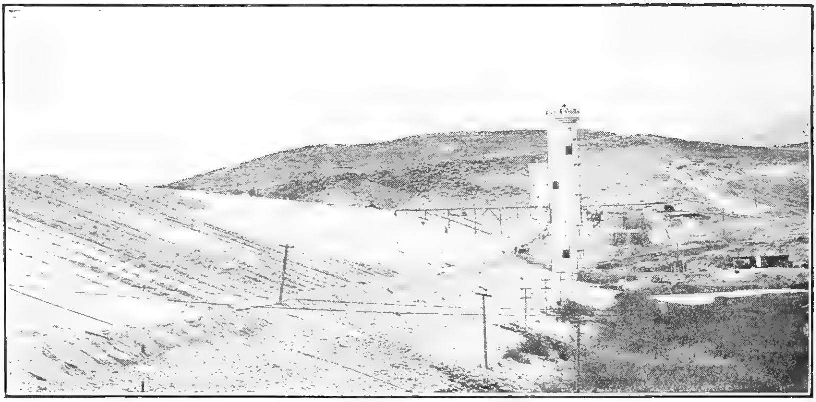

FIG. 3.—SAN FERNANDO RESERVOIR, LOS ANGELES SUPPLY.

Outlet towers shown at right center and at right end of dam.

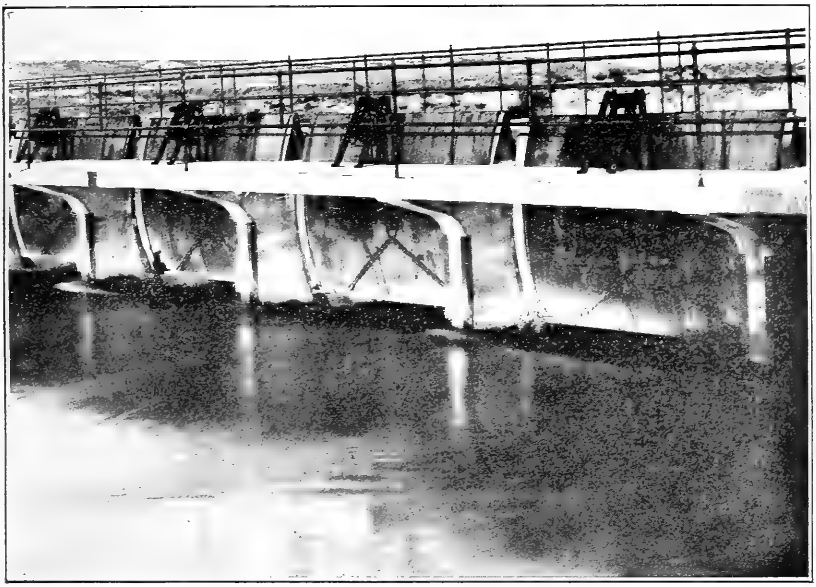

FIG. 1.—RADIAL GATES USED AS CONTROLLING DEVICE ON SPILLWAY CREST.

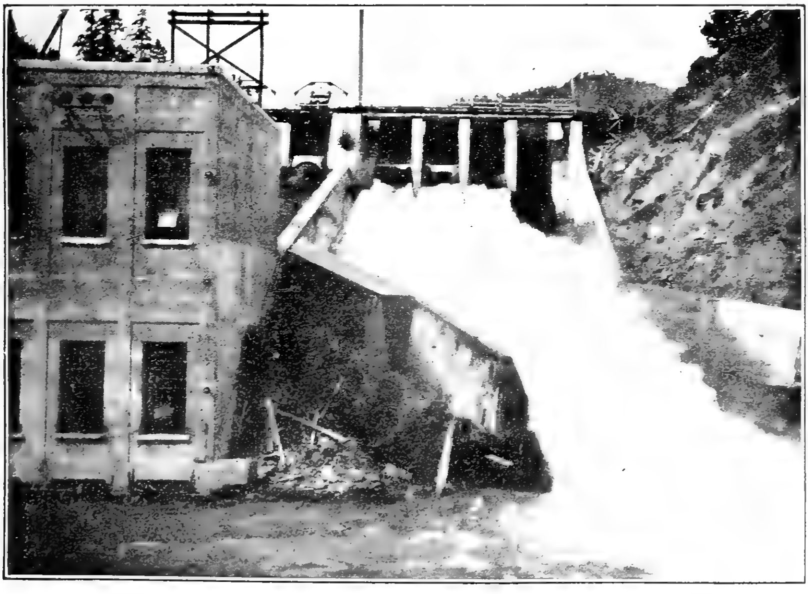

FIG. 2.—RADIAL GATES ON SPILLWAY OF POWER DAM.

Showing gates and wasteway of the Northwestern Power Co., Port Angeles, Wash.

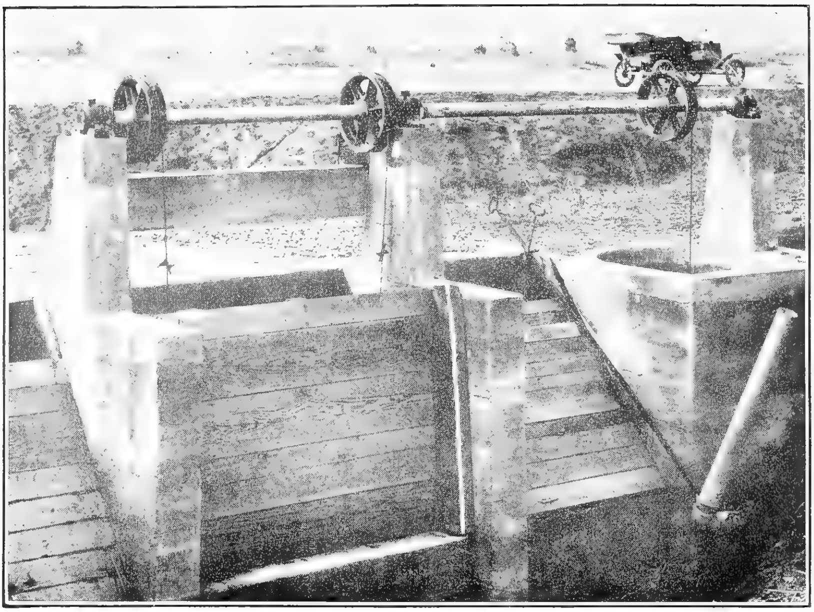

FIG. 1.—AUTOMATIC REGULATING GATE ON IRRIGATION CANAL.
Turlock Irrigation District, California.

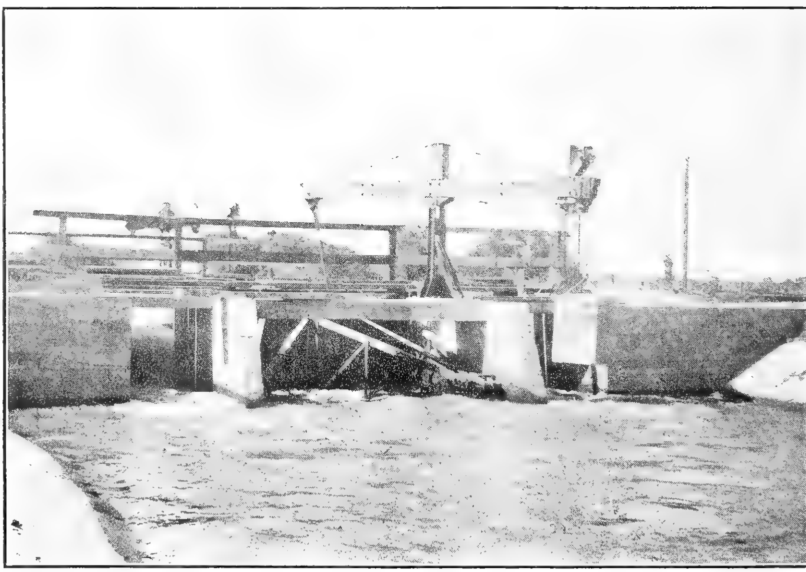

FIG. 2.—AUTOMATIC GATE ON DISTRIBUTING SYSTEM.
South San Joaquin Irrigation District, California.

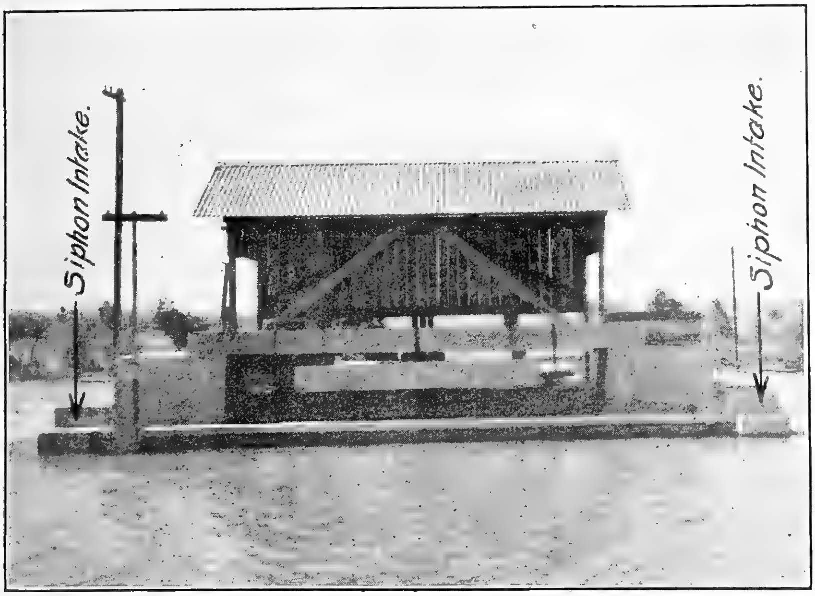

FIG. 1.—AUTOMATICALLY OPERATED GATE WITH SIPHON SPILLWAY ON EACH END.

Located on main distributing canal, South San Joaquin Irrigation District, near Ripon, Calif.

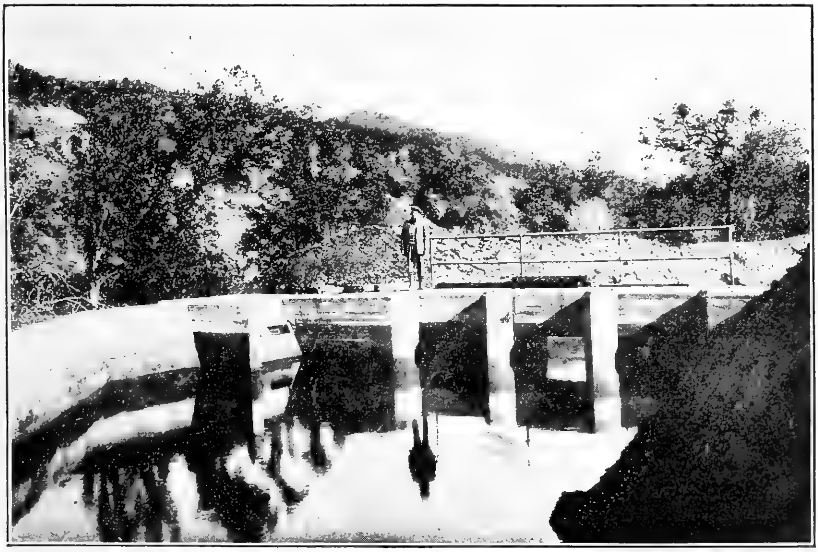

FIG. 2.—CHECK GATES AND INTAKE OF SIPHON SPILLWAY, ORLAND PROJECT, CALIFORNIA.

Intake lip of siphon is submerged and only air inlet shows at left of picture. Note close control of water level indicated by water line on structures.

above to water surface below the dam. Flow through a siphon is produced by the difference in the elevation of the water surface at the inlet of the siphon and the elevation of the water surface at the

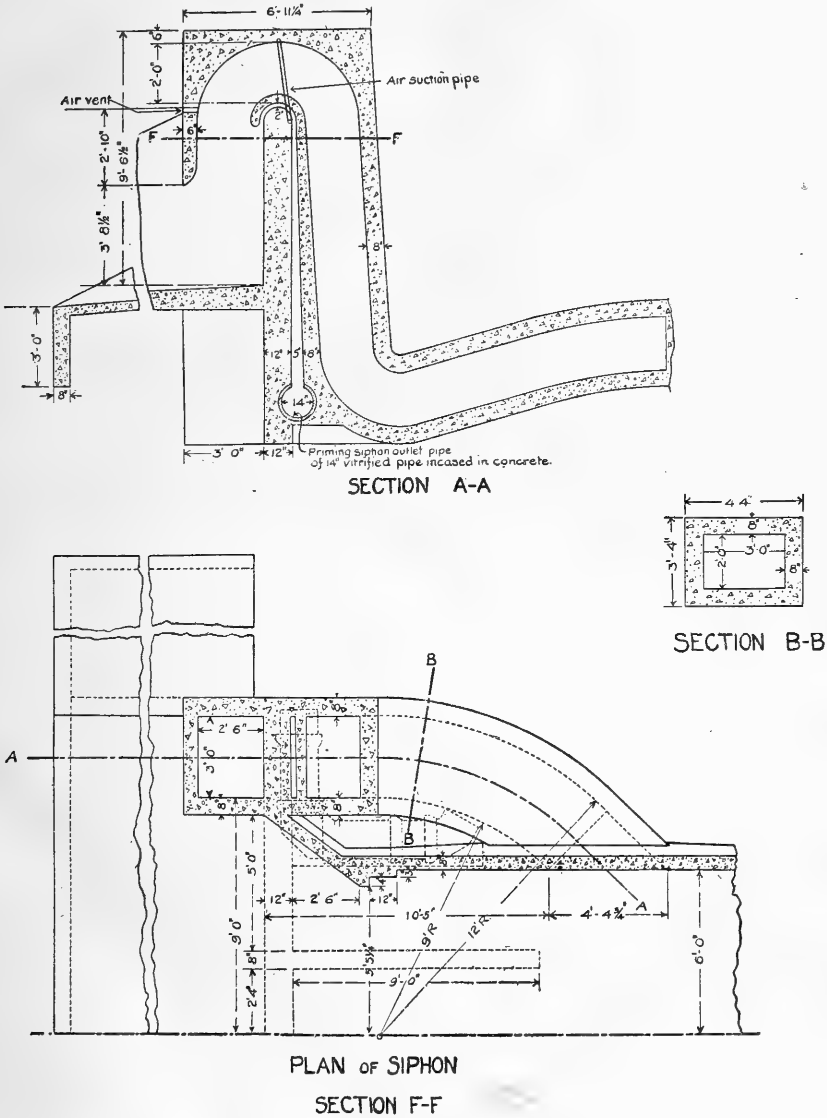

FIG. 5.—Cross-section and section plan of siphon spillway. South San Joaquin irrigation district, Ripon, Calif.

outlet end; or in case the latter is not submerged to seal the siphon, and the water has a free discharge, it is measured to the center of the outlet opening. In such cases the flow is treated as if it were through a short tube with various forms of inlet, and further limited

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by a well-defined range of velocities at the throat which can not exceed that resulting from a complete vacuum. The tendency of design has been in most cases to assume that heads in excess of 34 feet were not adaptable to siphon installation, because it was accepted that the limit of vacuum draft had been reached at that point. As a matter of fact, siphons have been built with heads beyond 34 feet and in specific cases from 36 to 52 feet, but always, of course, with a resulting decrease in the coefficient of discharge due to added frictional resistance. It is generally accepted from a study of numerous designs that two forms of siphon tubes may be considered. The first of these will be treated as having throat and outlet of equal cross section, but not necessarily of uniform shape. Such a design has rarely been used in this country, but is rather common in Europe and is more or less followed in the development of the Ocoee River installation in Tennessee.[1]

The second type has a contracted throat section, expanding with a divergent tube as the outlet and further modified to overcome local losses of head, or contributing defects. There are numerous examples of the latter type, and their installation has been generally adopted in the United States and in Europe, so that most of the experiments conducted to determine efficiency, or the lack of it, have been on this type. Certainly all of the siphons which have been designed to date have been planned on the general principles of hydraulics, and still there is a dearth of information by which the designer may be guided in selecting the proper proportions for the vital parts, or in departing from present practice with any assurance of increased efficiency or the accomplishment of a desired purpose.

Nothing is definitely known of the relative head losses in the various parts of the siphon; the intake opening, the entrance leg, the throat, the vertical or sloping outlet leg as the case may be, that due to shock or bends, or the curved discharge end. The effect on efficiency of a contracting or enlarging section beyond the throat is unknown, although such siphons have been built in this country. No experiments on working models have ever been conducted to determine other than the over-all efficiency, as valuable as such information would be when it is considered that the slightest change in the form of some part of a hydraulic structure will very often make the greatest difference in efficiency. Of course, it is in the long run only the efficiency of the structure as a whole which is desired, and the problem is solved, other than the value of having such information as will assist in arriving at the most economical design or in making designs conform to some additional specification as to speed in bringing the structure into operation and maintaining certain variations in allowable water surface.

[1] See description Engineering Record, May 16, 1914.

The formula $Q=kA\sqrt{2gH}$ is used as the basis for figuring discharge. While this expresses the quantity discharged, the accurate design of one of these structures will necessarily require more thorough search into the theory of the hydraulic features such as would enter into any tendency to retard flow and thereby reduce the efficiency of the whole structure. Coefficients, as has been stated above, have merely been assumed, and it is to be regretted that more data have not been developed to prove just how correct this practice has been. Forms and dimensions of the different functioning parts must necessarily be deduced from theoretical considerations, and on the results of data obtained from practical installations of such structures as have furnished any such information.

Theoretically, fixed rules have been adopted and practice has shown the advisability of having the overpour crest of the throat at the same elevation as the normal water level in the reservoir. For starting siphonic action the inlet must be sealed by the water as soon as the water in the reservoir rises above this normal height and climatic or other conditions may make this a matter of choice as to which of two methods will be used. The inlet lip can be made to extend down to the normal water surface or a very slight distance below it, so that when the water drops below this level the air is admitted and siphonic action ceases; or the inlet lip is extended to a considerable depth below the water surface, and the highest point in the crown of the siphon is connected with air inlets either fixed or regulated to admit air to the crown at the desired stage of water surface and break siphonic action. This latter case is used and is desirable when floating material may interfere with the proper action of the siphon. The contrast in the two designs is shown by text figures 6 and 7 as installed in Europe.

The discussions the writer has had with various engineers who have designed and installed siphon spillways have led to the belief that the assumed coefficients have been uniformly low; that refinements to a reasonable degree would lead to higher efficiencies; and that data to determine the reliability of coefficients of discharge and possibilities of future design must be obtained from existing installations. Any attempt to discuss the ideal proportions of the parts of a siphon spillway in order to approach the maximum efficiency would only revert to the general assumptions taken from formulas whose applicability has not been proven, but merely taken in all cases as being adaptable to this comparatively undeveloped structure.

In a series of experiments carried on at Throop College of Technology in California and at Fort Collins, Colo., several small models of siphon spillways were tested and some very interesting information obtained, proving that the conclusions from standard formulas to develop the proportionate dimensions of the various parts were reasonably well founded. The Throop College experiments were conducted by Mr. R. N. Allen, a student of the institute, as a basis for a thesis, and were directed by Professors Ford and Thomas, also of the college, and Mr. Louis C. Hill, of Los Angeles. The Fort Collins tests were conducted by the writer, at the cooperative hydraulic laboratory of the United States Bureau of Public Roads and the Colorado Experiment Station and, of course, all of these tests must be given only such weight as would result from a laboratory rather than a working model. They will tend to encourage research

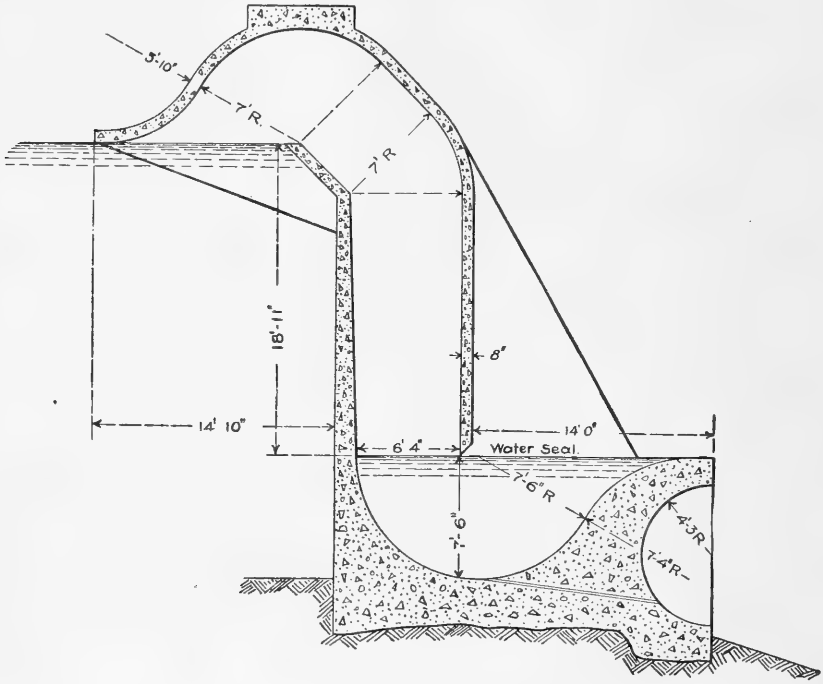

FIG. 6.—Cross-section outline of Lagolunga Reservoir siphon spillway. This is a typical example of the siphons installed in Europe where there is no trash or floating ice to clog the throat.

to develop the proper data from tests in a full-size structure, and suggest the study of such points as were not touched upon in the laboratory tests and will also stand as a guide to the finding of causes for the peculiar behavior in the smaller models. Great care was exercised in the design of the model siphons to obtain theoretically correct proportions for the intake, throat, outlet chamber, and outlet opening, both with and without the lower seal.

In the models for the Throop College experiments corrections were made for the friction coefficient of the materials as shown in standard tables. The outline of one of the models is shown in figure

1, Plate XII, and the arrangement of piezometer tubes and gage board in figure 2, Plate XII. A diagram of the testing laboratory and the setting of the siphons on the crest is shown in figure 1. Plate XIII.

The Fort Collins models were larger than those at Throop College and were designed as a miniature of the Phoenix siphon shown in figure 8 and hinged to permit of changing the shape of the outlet leg.

The tests were conducted to ascertain:

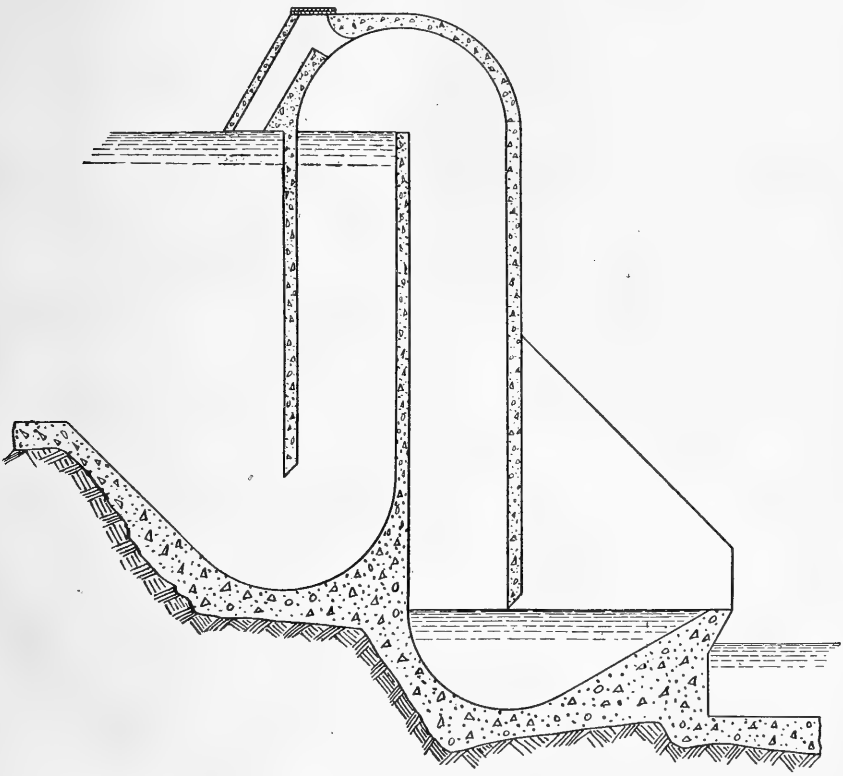

FIG. 7.—Outline section of type of siphon spillway built by Gregotti in Italy. Note submerged intake lip and surface air control intended for use where floating trash or ice interferes with operation.

(*a*) The theoretical and actual loss of head in the various parts.

(*b*) The effects of various shapes of parts upon head loss in that part and upon the general efficiency.

(*c*) The total efficiency of the structure and to determine a value for k in the formula $Q = kA\sqrt{2gH}$ for different shapes.

(*d*) The relation between the depth of submergence of the discharge lip and the depth of water over the throat to bring the siphons into action under different conditions of air inlet.

(*e*) The relation between the depth of submergence of the discharge lip and the speed of priming with various depths of water on the throat and various conditions of air inlet.

(*f*) Any additional relations which might become apparent.

COMPUTATIONS FOR DESIGN.

The calculations for the design of the models were varied to include a uniformly enlarging cross section of the outlet leg, then decreasing this to a uniform and finally to a converging section for the different tests. The formula $Q = kA\sqrt{2gH}$ was used, with A indicating the area of the throat in this case, but which may be taken as the cross-sectional area of the outlet leg, using, of course, the corresponding coefficient of discharge, depending upon the shape of the siphon and the extent of divergence or convergence.

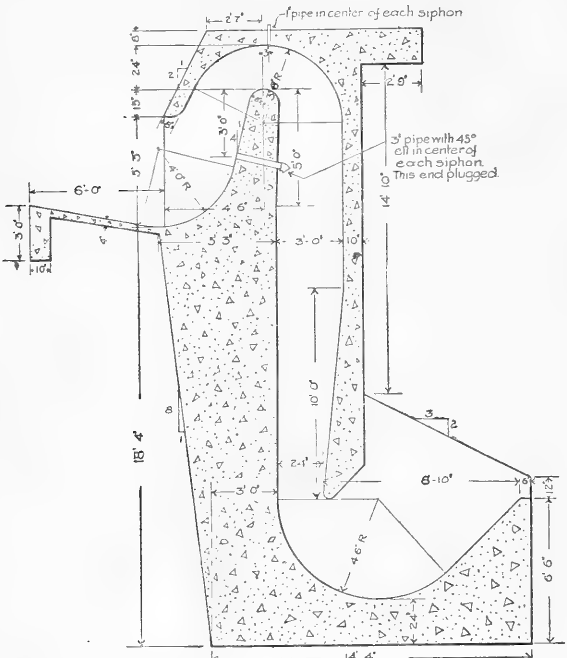

FIG. 8.—Cross section of siphon spillways, Arizona Canal, U. S. Reclamation Service, near Phoenix, Ariz. Installed to control the flow of canal at Arizona power plant. Note the converging outlet of the discharge chamber. Sketch shows air-control valves removed.

The effect of a properly expanding outlet leg is to increase the coefficient of discharge, calculated to produce results showing it to be greater than unity, and in siphon construction the extent of throat contraction is limited by a maximum throat velocity equal to that produced by a perfect vacuum.

Assuming that the operating head is relatively large, so that the outlet velocity will approach the highest throat velocity, the degree of expansion need be small, and in fact it may be advisable to make the outlet leg convergent, as was done on the final design of the installation of the Salt River siphons (fig. 8).

Data as to the effect of such practice have not been published. In the lower operating heads the outlet velocity may be low and it may be desirable to construct the throat area in a contracted form to such an extent that the throat velocity will approach the maximum velocity as induced by a perfect vacuum. On one such installation known to the writer, where the most minute study was given to the computations for the design of the different parts of the siphon, and the maximum available head for producing velocity was 11.87 feet, the mercury gage used on a test of the structure indicated a partial vacuum equivalent to 15.60 feet. This was noted as suggesting that the siphon was acting in a manner similar to a compound diverging tube under pressure, and yielding a coefficient of discharge greater than 1 and which may even have approached $1\frac{1}{2}$ or 2.

As stated above, in a discussion of the computations for the proper proportioning of the parts, one may go thoroughly into the theoretical determination of their dimensions, but must come back to the realization that the data are too meager to justify any conclusions and surrender to the simpler formula based on the elements of cross section, velocity, and a predetermined constant.

If H represent the effective head—that is, the difference in elevation between the water surface at the inlet of the siphon and the surface in the tail water or the mid point of the outlet end (depending upon whether or not the outlet is submerged)—we may express the losses due to all causes in the passage of the water through the siphon as follows:

$$H=\frac{V^2}{2g}+H_0+H_1+H_2+H_3+H_4$$

In the above equation V is the velocity at which the water leaves the tube; H_0 is the loss of head at entrance; H_1 the loss due to friction; H_2 the loss due to enlargement of section; H_3 the loss due to contraction; and H_4 the loss of head due to bends.

Velocity of approach has the same influence on a siphon spillway as on a crest spillway, but this influence is so small compared to the influence of the head of elevation that it can be ignored.

Because of the fact that the outlet basin of most siphons is so constructed that the velocity head is completely dissipated in eddies, no mention is made of any recovery of velocity head. This formula, therefore, accounts for the elements which hydraulicians agree contribute to form a factor of efficiency for the structure as a whole.

No tests on other than laboratory models have been conducted to obtain correct results of the actual application of the factors, or to what extent they are influential.

It is assumed that an ideal inlet will be largely flared and then taper to the smallest cross section of the siphon, which is usually at the throat, because it is known that from tests on pipes of small cross section and of different materials the entry loss for a bell-mouthed intake will approach a value of $0.05H_v$. The value $0.25H_v$ has been assumed as the extreme limit for loss from shock or bend, but this has not been proven, in pipes of large diameter. Whether or not the assumption is correct can not be stated, and is here taken to apply where the radius of curvature is at least equal to the height of the throat, and this coefficient is based on the velocity at the throat (V).

The friction loss in the outlet leg depends upon the material and class of workmanship therein, and is further dependent upon the cross section of the chamber with regard to the throat, which is assumed as constant and equal to the area of the throat.

RESULTS OF TESTS.

The writer has stated in another part of this paper that the only tests made to determine the losses on the different parts of the siphon are those of the small laboratory models, so that in summing up the results reference will be made to the tests of overall efficiency on working models built to discharge large volumes of water whereever such information is available. Some points have been brought out incidentally in these larger tests, indicating the value which may be placed on the deductions drawn from the laboratory work. Taking these points up in the order in which they are listed in a former part of this paper, the following is a summary:

(*a*) The theoretical and actual loss of head in the various parts of the structure as determined from the tests were not consistent for the various tests nor for the different models, but were of sufficient accuracy to warrant the use of the standard formulas until some more reliable data can be developed. The standard formula for the loss at entrance head $0.50H_v$ for the type of opening for which the formula was developed ran both high and low in the tests, and may be considered as holding good as an average, so far as any developments in the laboratory results are concerned. Friction loss in the structure was indicated as being negligible in the larger sections of the tube, and was heaviest at the throat or contracted section. It was so small as to be neglected in the results.

(*b*) The varied shapes of the discharge lip did not seem to affect the total efficiency, and since all of the models were of uniform design at the intake end, nothing developed in the tests at that point or in the bends from which to draw conclusions. No data from models of larger siphons are available with which to compare these.

(*c*) The total efficiency for the various models for different air-inlet conditions ran 0.84, 0.98, and 0.983 for the three sets of tests when grouped and averaged. Similar tests on larger models, but without the introduction of varying air-inlet conditions, ran from 0.644 to 0.805, and in a number of other siphons in this country and in Europe coefficients of discharge ranging from 0.70 to 0.82 have been found. These points will appear in the descriptions of the individual cases hereinafter taken up.

(*d*) The commonly accepted theory has been that the flow of water over the crest of the siphon would exhaust the air through the dis-

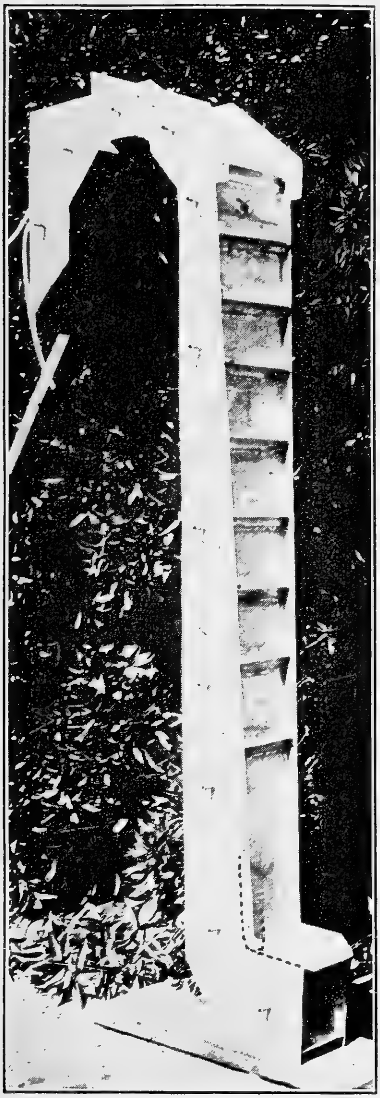

FIG. 1.—MODEL OF TESTING SIPHON.

Dotted line at foot of model shows approximate shape of discharge lip of the models used in the Throop College experiments.

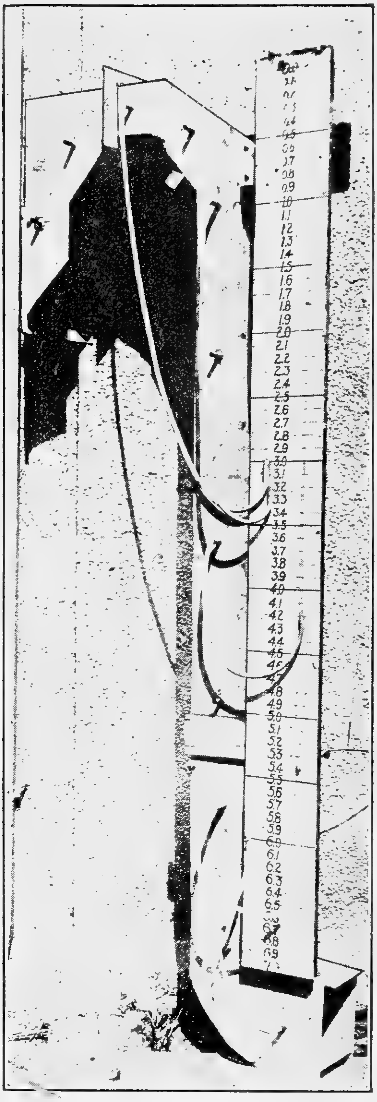

FIG. 2.—MODEL WITH GAGE BOARD AND SEVERAL PIEZOMETERS ATTACHED.

Connections for piezometer tubes were of $\frac{3}{8}$-inch brass tubing soldered flush to the inside face of the siphon.

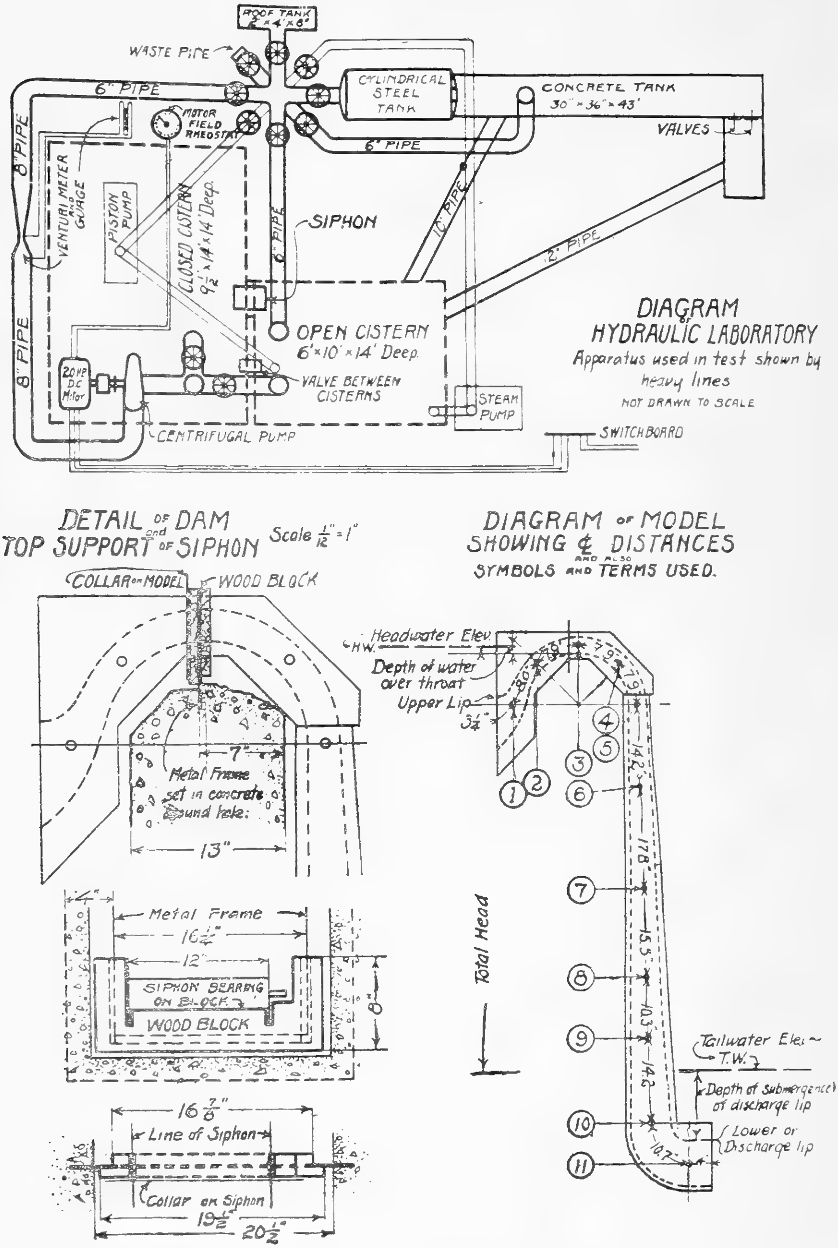

DIAGRAM OF TESTING LABORATORY AND SETTING OF SIPHONS ON CREST.

For experiments on models at Throop College (California).

charge leg and under the discharge lip, provided the outlet leg was sealed at that point and that the air becoming rarefied would encourage an increase in this flowing head until full siphonic action was accomplished. The tests on the laboratory model indicated a tendency to develop a back pressure in the crown by this rise of the water surface at the inlet, and the suppressed effort of the air to escape under the discharge lip when the seal was complete.

In fact, it was shown that with the discharge lip submerged 0.1 to 0.2 foot, and fully out of water, resulting in the tube being unsealed, the siphon primed easier and quicker than when the outlet lip was submerged to increasing depths to effect more complete seal. The tests on the Yuma siphons indicated that this is probably true, but the head on the discharge lip during the Yuma tests was not reduced sufficiently to disclose its action with sealing heads of 1 foot or under, or when flowing freely into air. The Ocoee River installation of the Tennessee Power Co., however, does bear out the tests of the small models, although it has been argued that the shape of the outlets of these siphons in itself forms a seal. Conclusive proof that a sealing basin is not necessary on siphon spillways or that the efficiency of the structure is not decreased by the absence of it, would lead to a great reduction in their cost and would permit of the elimination of another weak point in freezing weather.

(*e*) The placing of air inlets and the submergence of the outlet end are so closely related that the points are difficult of separation in summing up the results. One question to be solved is to determine the proper depth of submergence of the discharge lip to produce maximum siphonic action, and another is to determine the shortest period of time necessary to produce complete action under the same conditions. To enable the plotting of a curve to show these relations, various conditions were produced by the manipulation of improvised air inlets, made possible by utilizing the tubing for connecting the gage glasses. With all air inlets or outlets closed over the throat section, it is intended that the siphon will come into full action just as the water flows over the crest. The condition as developed with a complete seal of the siphon tube and with the water rising in the inlet and outlet legs produced an air compression in the tube which tended to retard the increase of head on the overflow crest, and consequently required a longer period of priming because of the resulting decreased flow of water necessary to produce expulsion of the confined air in the tube. The shortest period of priming was obtained by using the gage-tube connection at the throat as an automatic air valve, allowing all compression in the siphon to be relieved when the water rose to produce it, and then to be instantly closed when a reverse pressure was started.

(*f*) This suggested that the delays in priming were shortest when a relief valve was provided; that the heads on the crest of the throat necessary to effect a complete priming were less under such conditions or when the outlet lip of the discharge leg was so deeply submerged as to set up reverse action in the expulsion of the entrained air.

Since the tests referred to were made a system of relief valves has been installed in connection with the battery of seven siphons placed in the Huntington Lake dam in California, the discharge from which amounts to 5,000 second-feet. The description of these siphons follows in another part of this paper.

SIPHON AT GIBSWIL, SWITZERLAND.

A siphon at Gibswil in Switzerland, built with a sloping instead of a vertical outlet leg, is described as consisting of a $\frac{1}{4}$-inch riveted steel tube tapering from 31.5 to 23.6 inches in diameter, the assumption being that the taper would tend to keep the water column from parting under the 52.48-foot head which was utilized. The inlet pipe was cut on a horizontal plane at the normal high-water surface and was incased in a reinforced concrete hood projecting 3.28 feet below normal water surface, so as to prevent the entrance of ice or floating débris. The air control, to break the action of the siphon and to prevent the water from being drawn down into the reservoir below normal surface, consisted of long narrow slots cut through three of the sides. When the water rises these slots are closed and siphonic action begins. A series of tests to determine over-all efficiency for this siphon gave a discharge of 98.9 cubic feet per second, but this was considered inaccurate and lower than the real efficiency of the siphon, because it was found that some of the air slots were not fully sealed. A maximum efficiency yielding 123.6 cubic feet per second was determined as a more accurate assumption of the real capacity. Computation of the end area at 3.03 square feet would give a corresponding velocity of 40.8 feet per second. The velocity due to 52.48 feet head is $V=\sqrt{2gH}=58.06$ feet per second and thus the efficiency k is $\frac{40.80}{58.06}=0.70$ as a coefficient of discharge. The computed friction loss in the pipe alone equaled 10.2 feet, which certainly is high and confirms the statement made in another part of this paper that the increase in the length of the tube beyond 34 feet would reduce the value k. In addition, this tube had the added friction produced by building the draft tube on a slope and thus making it longer.

In another siphon installation, also in Switzerland, the conditions to be overcome as the result of conflicting requirements of several plants and their water rights, were peculiar. There was a spinning and weaving mill operated by hydraulic machinery, the tail water from which, up to a maximum of 56.5 second-feet, was appropriated by a twine plant farther down the stream. The discharge from the first plant in excess of the 56.5 second-feet had to be led over a weir spillway 230 feet long and through two sluiceways into the canal of still another plant of a hydroelectric company. Obligations fixing the disposal of the water over the spillway provided that the head must not exceed 2 inches, and since on the one hand the discharge was variable with 160 second-feet as a maximum, the demand of the power plant for water was also variable, so that close regulation and continuous attention were imperative. The power company had built a 20-foot spillway, but the water often rose 10 inches above the permissible stage and thereby interferred with the operation of the plant above. To eliminate the disadvantage to all concerned, the twine mill built a siphon for a computed discharge of 70.6 second-feet and the power company built one for a computed discharge of 88.3 second-feet. The latter was built on the old spillway, which was broken through and covered with a reinforced concrete hood. The head between pond and tail water was only 4.92 feet, but the completed structure gave a test discharge of 91.8 second-feet. The cross-section of the siphon was uniform and of an area of 9.47 square feet, giving an actual velocity of 9.7 feet per second and corresponding value of 0.55 as a velocity coefficient. This case is described in detail to illustrate the adaptability of the structure and to emphasize its value in just such cases of conflicting regulatory requirements, of which there are many.[1]

TENNESSEE POWER COMPANY'S SIPHONS ON OCOEE RIVER.

Where the canal of the Tennessee Power Company crossed a ravine it was necessary to design a structure capable of spilling from 1,300 to 1,400 second-feet. The structure must also take care of a rise of 1 foot in water elevation in a period of 8 seconds in case the power plant just below it should be suddenly shut down or in case of stoppage of flow due to slides or other obstruction just above the forebay. The 1 foot referred to was the limit of freeboard in the canal at the point. An overflow spillway capable of satisfying the conditions would have been 400 feet long, and since the available space in which the structure had to be placed was insufficient, a battery of 8 siphons, each having a throat cross-section of 8 square feet, (1 by 8 feet), was installed, with the addition of a sand gate. The operating head on four of the siphons was 27.2 feet and on the remaining four 19.2 feet and the draft resulting produced an increased velocity corresponding to the difference in elevation between the water surface in the forebay and the center line of the siphon outlets, minus the usual losses due to entry, bends, friction, etc. The vertical draft tubes change gradually from the throat cross-section at its upper end to 4 by 2 feet at the lower end, where it connects

[1] Data taken from a paper by Herr J. Huber and published in Engineering News, May 3, 1913.

with the flaring outlet. In each unit the inlet is well submerged, with its upper end 5.5 feet below the water surface. The inlet is 3.5 feet high and 6 feet wide, protected by a vertical screen with $\frac{3}{8}$-inch bars spaced 4 inches center to center. The over-all efficiency was tested using the formula $Q = kA\sqrt{2gH}$ and gave a coefficient of discharge of 0.65. These siphons are not provided with water seals on their outlet ends, but have free discharge. The whole structure, gate included, was placed in a length of 90 feet and the cost was one-third that estimated for the overflow type of spillway.

UNITED STATES RECLAMATION SERVICE SIPHONS.

The United States Reclamation Service has located a siphon about 12 miles below the heading of the Yuma Project, where the main canal leaves the foot of the mesa and turns southward toward Yuma. At this point there is a drop of about 12 feet in water level, bringing the canal to the level of the lower valley. It is intended to develop power here to be delivered to a point below Yuma and used for pumping water from the main canal through a lift of about 80 feet to the top of the mesa, for the irrigation of some 30,000 to 40,000 acres of land. A battery of 5 siphons has been installed. They can be adjusted to discharge at different levels and all employed when the canal is running full, the combined theoretical discharge being 1,488 second-feet. They have been tested operating as a battery at efficiencies ranging from 68 to 70 per cent and in combinations from 64 to 80 per cent. The area of the smallest or throat section, which was used in the computations, is 11.35 square feet, and at the outlet end 21 square feet. In the tests for efficiency the actual drop between water surfaces was 11.87 feet, which was certainly all the head available for producing velocity, but the partial vacuum registered by the mercury gage showed an equivalent of 15.60 feet of water.

This was noted as indicating that the siphon was acting in a manner similar to a compound diverging tube under pressure and having a discharge coefficient greater than one and which may even have been greater than two. It also indicated that the draft tube should flare, which was the case in this instance. The observed depth over the lip of throat necessary to start siphonic action was 0.35, 0.40, 0.35, 0.15, 0.35, and 0.40 foot respectively for the siphons as listed above and with 5.35 feet of water over the lip of the outlet, and they ran uniformly one-tenth foot higher in each case with the outlet sealed with 6 feet of water. They are of reinforced concrete and cost about $23,000 complete. The regulation of siphonic action is by means of a specially designed sliding air valve shown in figure 9. This same design is used on the installations at the Salt River project near Phoenix, Ariz. The operation of these control valves was satisfactory, except that there was not enough vertical movement to permit of a wide range of regulation of the water surface and floating trash had a tendency to enter and clog the neck of the valves. Screens fixed on their lower ends removed the difficulty.

On the Sun River project there is a structure on the main canal, shown in figures 1 and 2, Plate XIV, and in cross-section in figure 10, which combines a storm culvert, sluice gate, and siphon spillway. The canal at the point of installation has a maximum capacity of 1,000

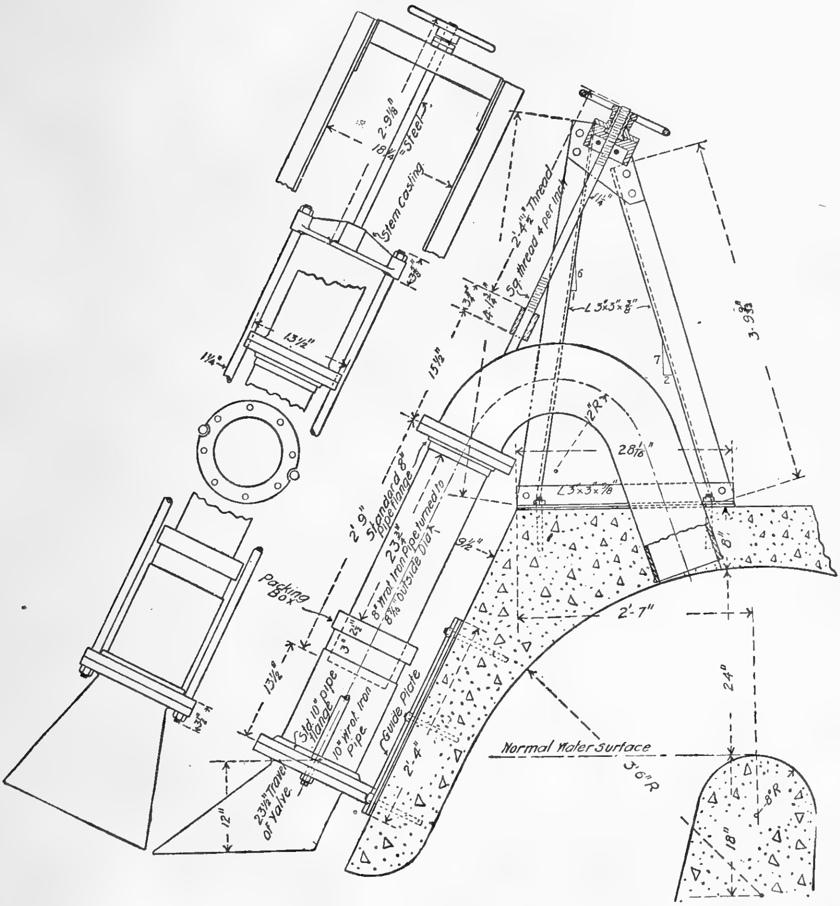

Fig. 9.—Air-control valves to start and stop siphonic action. Installed on siphon spillways of U. S. Reclamation Service near Phoenix and Yuma, Ariz.

second-feet, and the siphon is designed to dispose of any water in excess of that amount up to 1,500 second-feet, because the combination of the three siphons is calculated to discharge 500 second-feet. To provide for any possibility of silt deposit at this point, the three sluice gates, each 3 by 3 feet, operating under a head of 11 feet, will discharge about 500 second-feet and the culvert which conducts the flow to a natural drainage channel is designed for capacities of 900 and 1,400 second-feet at the intake and outlet ends respectively. The siphons are to operate under a head of 12 feet, at an average velocity of about 14 feet per second, assuming 0.50 as a coefficient of discharge. The structure is of reinforced concrete throughout, with a detached air chamber for the regulation of the siphons. The air control has not given satisfactory results because of its isolation; otherwise the structure is a good example of the combination of facilities for the control of superdrainage on sidehill canal or where melting snows or obstruction below the structure might cause an abnormal rise of the water level in the canal at the site of the siphon.

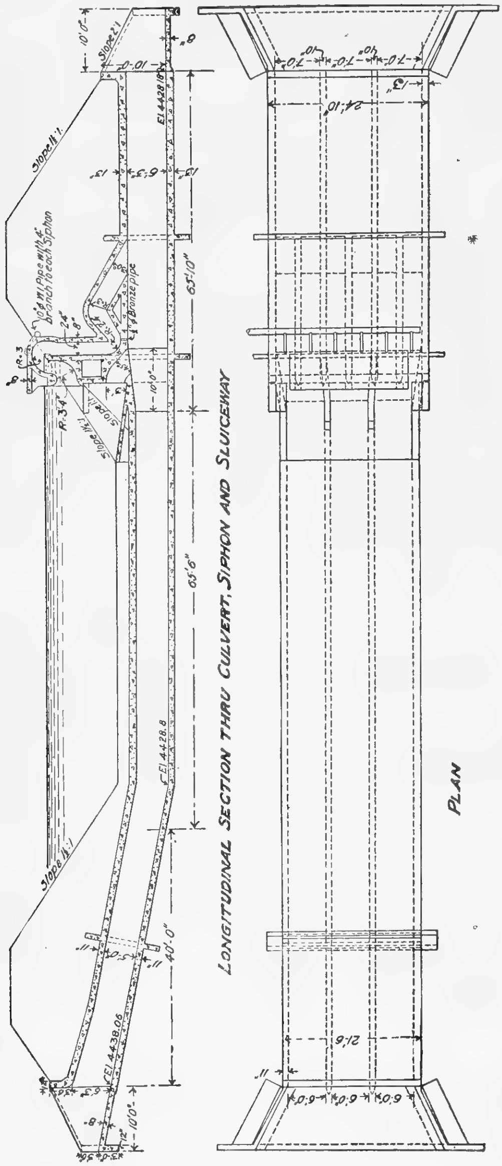

FIG. 10.—Cross section and plan of combination storm culvert, sluiceway, and siphon wasteway. Built on main canal of the U. S. Reclamation Service, Sun River project, Mont.

A structure to regulate the Arizona Canal of the Salt River project, at the Arizona Power Plant, is shown in figure 8. The area of the throat section is 10 square feet, flaring to a maximum section of 15 square feet at a point 10 feet above the lip of the outlet, where it tapers to the same form and cross section as that of the throat. This is the only case of the tapering draft tube known to the writer and it is to be regretted that there is no information as to the efficiency of the structure. Such a series of tests as would give results enabling the engineering profession to ascertain the effects of this departure and verify or correct the theory of the parting water column in siphons under relatively high heads would be of benefit, and the tests taken on the Yuma installation, where the design is identical except for the converging outlet, could be contrasted.

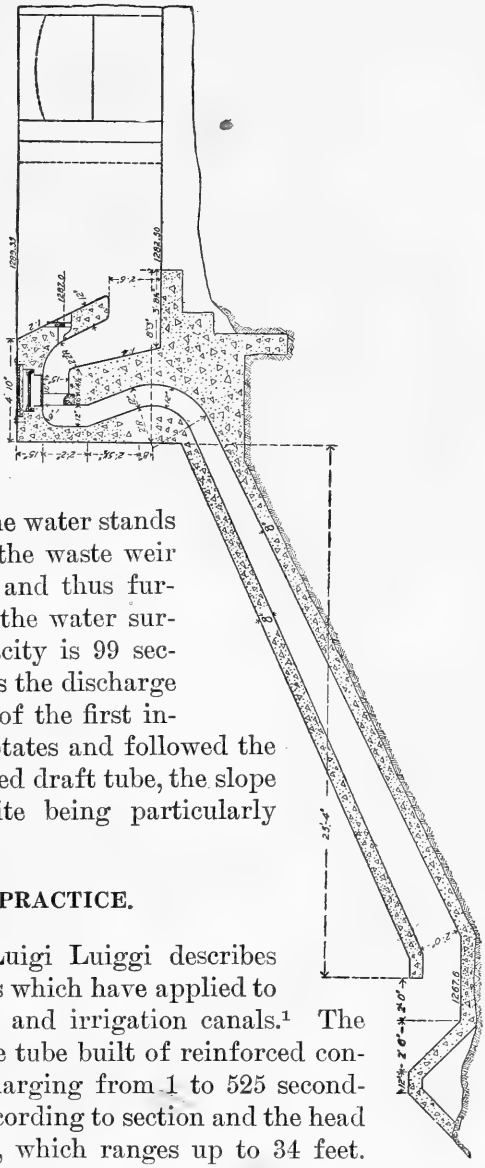

Fig. 11.—Cross section of siphon spillway, headworks East Park supply canal, Orland project, California.

As a method of automatically safeguarding the freeboard of a canal at isolated points, the small siphon shown in figure 2, Plate XI, and in text-figure 11 is a good example. These figures illustrate the siphon at the head of the East Park Feed Canal of the Orland project. It is designed to operate when the water stands 0.2 foot above the top of the waste weir at the place of diversion, and thus furnish a close regulation of the water surface. The estimated capacity is 99 second-feet, with 0.50 taken as the discharge coefficient. This was one of the first installations in the United States and followed the European custom of inclined draft tube, the slope of the ground at the site being particularly adapted to the design.

EUROPEAN PRACTICE.

The Italian engineer Luigi Luiggi describes numerous siphon spillways which have applied to dams and to many power and irrigation canals.[1] The prevailing type is a square tube built of reinforced concrete and capable of discharging from 1 to 525 second-feet, varying, of course, according to section and the head under which they operate, which ranges up to 34 feet. To produce larger discharges where head was limited, siphons are placed in batteries. A typical example of clever control by the siphon spillway is shown in the case of the Logalunga Reservoir, near Genoa,

[1] Transactions of the International Engineering Congress, 1915, Waterways and Irrigation Section.

where the old overflow spillway required a head of from 4 to 8 feet to discharge the freshets, and, as is usually the case where the overfall spillway is used, quantities of valuable water ran to waste over the spillway after each storm. A battery of 10 siphons, each with an internal cross section (fig. 6) 6 feet 4 inches square and a working head of 18 feet 11 inches has a calculated capacity of 5,250 second-feet. At the same time the sill of the spillway was elevated 3 feet, producing additional storage for about 240 acre-feet. This additional capacity is a very important advantage in places where water is valuable. It was, moreover, proved that the siphon gave a discharge of 525 second-feet when the water rose to 4 inches over the lip, which was a rise of 14 inches less than with the old spillway, thus reducing the water pressure against the dam correspondingly. The additional storage referred to above represented an income of at least $3,000 per year, and if capitalized at 5 per cent would produce a total of $60,000, or at least six times the cost of the new spillways. There are numerous examples of such possibilities in this country known to the writer where the siphon spillway should be considered.

In one of the large hydroelectric developments in the western part of the United States there was constructed a dam over 100 feet in height with a spillway section close to 600 feet in length. The maximum head on the crest with a discharge of 100,000 second-feet is 14 feet, with a freeboard of 4 feet. In other words, it was necessary to design the structure so as to limit the range of rise in the reservoir to 14 feet above the crest of the spillway and at the same time take care of the maximum inflow. With a battery of spillways of the siphon type such as was installed in the Sweetwater dam or the Huntington Lake dam, in California, at least one-half of the spillway area could have been saved with an additional storage of about 8 feet of water in the top of the reservoir, where each foot means an enormous amount of stored energy. In addition, much closer regulation of the pond level would have been provided.

In Italy the structure has been more fully developed and used, and it is stated that there are more than 100 siphon spillways in use in connection with Italian dams and canals.

HUNTINGTON LAKE SIPHON SPILLWAY.

Huntington Lake is located about 50 miles northeast of Fresno, Calif., and is formed by the construction of three dams impounding the waters of Big Creek, a tributary of the San Joaquin River. It has a watershed area of 80 square miles and an average annual precipitation of about 31 inches. The dams are of concrete, of the gravity arch type, two of them 100 feet in height and one over 150 feet

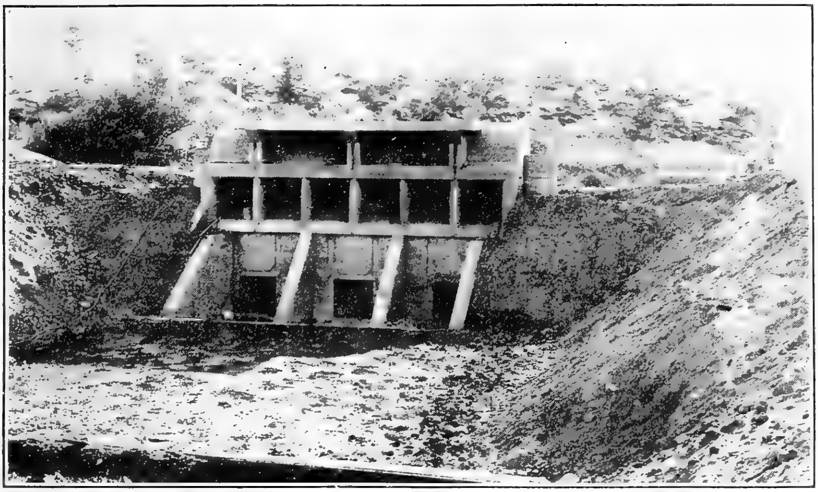

FIG. 1.—INTAKE END OF SIPHON WASTEWAY ON MAIN CANAL OF SUN RIVER PROJECT.

Note the three sluice gate openings referred to in the description.

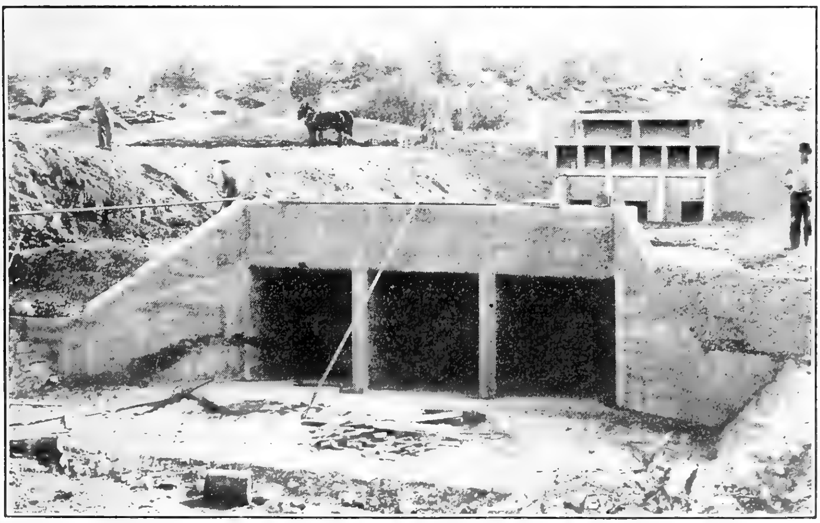

FIG. 2.—INTAKE END OF STORM CULVERT SHOWN IN FOREGROUND AND SIPHONS IN BACKGROUND.

FIG. 1.—OUTLET OPENING FOR OVERPOUR SPILLWAY AT SOUTH END OF SWEETWATER DAM, CALIFORNIA.

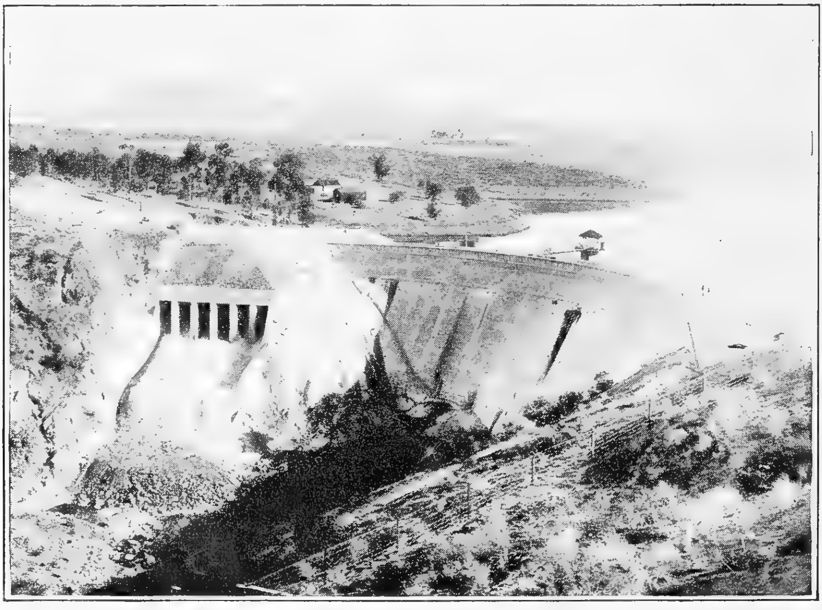

FIG. 2.—SWEETWATER DAM AS COMPLETED AFTER THE FLOOD OF 1915.

The outlet side of the battery of six siphons is shown in the picture on the left-hand side of the dam. This was added as additional spillway after the flood had cut a channel where the siphons are now located.

high, the latter being in Big Creek itself. In 1917 these dams were all raised 35 feet to an elevation of 6,955.5 feet. The dam known as No. 1 was the only one provided with a spillway, the other two being constructed above any possibility of overflow. An overflow crest 645 feet long was built in dam No. 1 over which flow begins after the water surface in the reservoir exceeds an elevation of 6,950 feet. The downstream face was built in a series of steps, each 4 feet high and 2 feet wide, and to prevent any great amount of water going over the dam, a battery of 7 siphons was installed to operate when the water on the spillway crest had reached a depth of 6 inches or more.

The cross-sections of these siphons are shown in figure 12, and it will be noted that they are not of uniform design in that five of them have the outlet legs inclined toward the intake and two of them slope away from the intake. They are all of reinforced concrete with throats 3.5 feet high and 12 feet wide, containing an area of 42 square feet. Because of the sloping topography of the canyon side where the siphons are built, they also vary as to operating head, three of them being designed to utilize 12 feet, two of them 15 feet, one 18 feet, and one 22 feet fall from head to tail water. The intakes extend 4 feet below normal water surface and are tapered from an area 9.25 feet high by 15.5 feet wide to that at the throat, 42 square feet, and the draft leg is uniformly of the same area as that at the throat. Except for extreme care in making the concrete dense enough to exclude air leaks in the siphons, no other precautions were taken to effect a special lining other than a coat of "gunite," which was applied after the forms were removed. Air control was provided by an 8 by 27 inch air duct connecting the upstream face of the dam with the crown of each siphon chamber, the top of the air inlet being at the same elevation as the overflow spillway crest. A sliding gate is fixed over these air ducts, the vertical movement of which is 16 inches, which makes possible the regulation of the siphons to a point that far below the point where siphonic action would ordinarily cease.

A peculiar condition was developed as a result of the varying heads under which the siphons were to operate in that the sealing basin of the upper, or lower-head, units would tend to overflow into the adjacent basins, causing a rise of water in the siphon chambers at the outlet end and transmitting adverse air pressure to the intake arm and resulting in the lowering of the water there and retarded priming of that particular siphon. To eliminate this condition there was installed a system of relief pipes connected with the crowns of the siphons so that any air pressure in one siphon produced by the action of another could be expelled by the siphon in action. This was sufficient for those whose outlets were of the same level, but the pipes for

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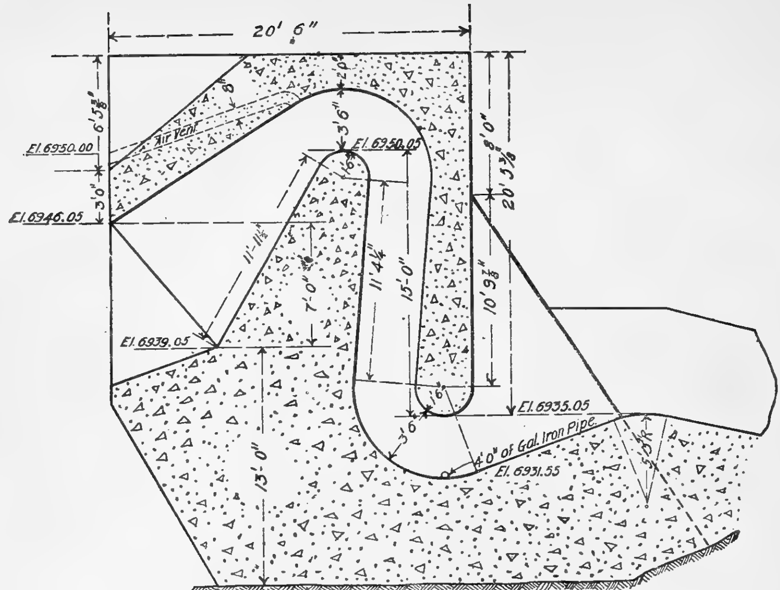
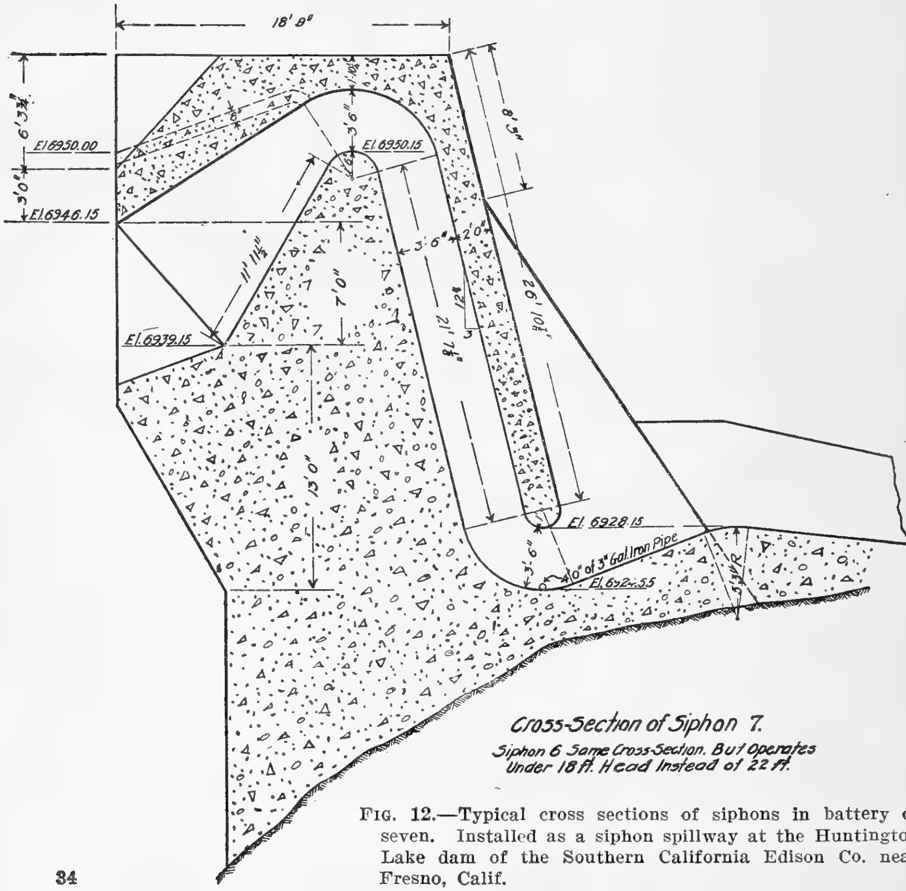


Cross-Section of Siphons 4 & 5.

Siphons 1, 2 & 3 of Same Cross-Section, but Operate Under 12 ft. Head Instead of 15 ft.



Cross-Section of Siphon 7.

Siphon 6 Same Cross-Section, But Operates Under 18 ft. Head Instead of 22 ft.

FIG. 12.—Typical cross sections of siphons in battery of seven. Installed as a siphon spillway at the Huntington Lake dam of the Southern California Edison Co. near Fresno, Calif.

the others were led to a point 2 inches under water where air pressure could be relieved but back suction after priming was retarded by the high lift. The calculated capacity of battery is 5,200 second-feet and since the project has been but recently completed no tests of efficiency have been conducted. It is evident that the assumed discharge coefficient was conservative. The siphons replace a system of flash-boards 6 feet high which were used before the dams were raised.

Figure 13 represents a smaller type placed at a number of points along the canal system of the Mount Whitney Power and Light Company in California. The operating head is 3.5 feet, the cross section 0.5 by 2 feet, and the approximate discharge 10 second-feet. Larger structures installed in batteries of three units are also placed along their canal system (fig. 14), designed along the same general lines, but capable of discharging up to 100 second-feet. The only trouble found with any of these was due to ice and floating trash which clogs the intakes, but which is seldom a great menace, since the structures are rarely in operation during the period of freezing weather. Figure 7 shows the outline of a typical European design such as was installed by Gregotti and as designed to overcome the objection where trouble may be expected from ice and floating trash. The air regulation is so arranged that it can be manipulated to break siphonic action when the ordinary air duct intake is menaced by ice. Provision is also made for the drainage of the water-seal basin to prevent freezing and consequent stopping of the outlet.

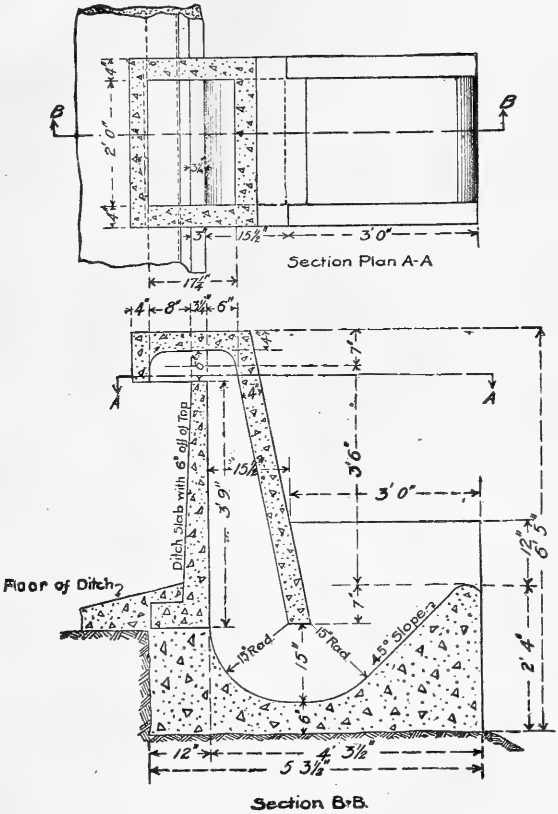


FIG. 13.—Cross section of siphon spillway to waste small amounts of water. Located at isolated points on the canal system of the Mount Whitney Power & Electric Co. near Visalia, Calif.

The claim that the siphon spillways constructed as control devices on the New York State Barge Canal were the first installations in this country is undisputed. This project offered several ideal cases for testing their adaptability in regulatory capacities and they were utilized in several locations where other and better known structures were either impracticable or impossible. Two of the three locations

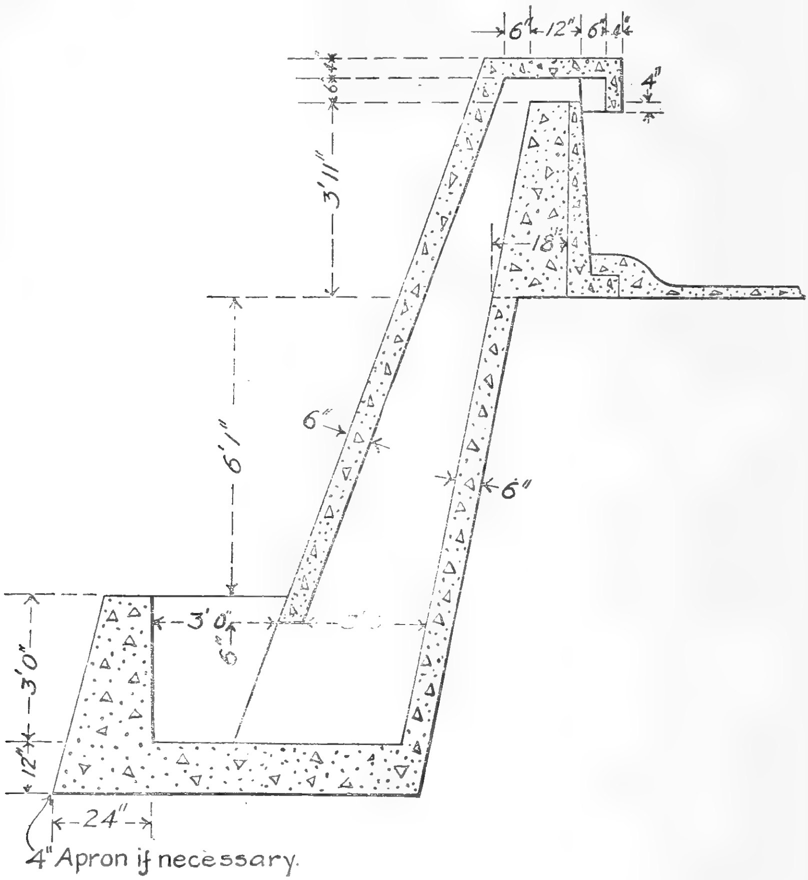


FIG. 14.—Cross section of larger size siphon spillway in battery of three. These are also located at points where automatic operation is essential, and as built and operated by the Mount Whitney Power & Electric Co. are capable of discharging 100 cubic feet per second.

required a structure capable of disposing of the waters accumulated from an intercepted drainage area and which had to be discharged into an adjacent stream. Surface fluctuation was limited, so that the overflow into the canal could not be in excess of the outflow and it had to be discharged with rapidity equal to the inflow. The old form of overpour spillway with the necessary length of crest to dispose of the water within the limits of surface rise and fall was impossible in at least one case because of the lack of area in which to build it. At this point it was estimated that the maximum inflow from the drainage area was about 700 second-feet, which the siphons must take care of during heavy rainfall and in addition limit the fluctuation of water surface to 1 foot. A weir to discharge the inflow stated, with the limiting head on its crest, required a length of 200 feet which was not permissible under the conditions and a spillway consisting of four siphons and a 20-foot waste weir for floating trash, required but 57 feet between abutments. Each siphon has a throat area 7.75 feet wide by 1 foot high and acts under a head of 10.5 feet calculated to discharge 160 feet. The 20-foot weir with the 1 foot head will discharge 70 second-feet, making a total of 710 second-feet. The inlet of the siphons is well submerged to prevent the entrance of floating bodies and is further protected by screens. The inlets were flared to twice the normal area to reduce to a minimum the loss of head due to entry, and the throat of the siphons were each made 1 foot high, because it was desired to retard full siphonic action until the tubes were completely filled at that point. They were flared again to a section of 2 feet by 4 feet at the outlet end. Air vents 6 inches high by 12 inches long were provided for each siphon, piercing the wall at low-water level, thus regulating the action at that point.[1]

Contrasting examples of requirements of overflow and siphon spillways are furnished in Italy, where the limiting lengths of spillway sites are in a ratio of about 6 to 1. The two plants in question are a hydraulic power plant near Milan, which is equipped with ordinary overflow spillway, and another at Verona with a siphon spillway. The siphon is confined within a space 59 feet in length and limits the surface fluctuations to 3 inches, while the overflow spillway at Turbigo, near Milan, is 300 feet in length and does not discharge the required volume until 2 feet of water pours over its crest. In addition the overflow spillway is supplemented by three gates automatically worked by electric motors.[2] The conclusion as to control devices is self-evident.

The battery of 6 siphons recently completed for the spillway at the north end of Sweetwater Dam, California (fig. 2, Pl. XV), is additional to the old overflow spillway on the south end, which in itself has been remodeled and extended as a result of the damage by the flood of 1915. There is also an emergency overflow spillway 500 feet long in the center of the dam. The siphon spillway is the largest of the type constructed to date, having an intake area for each unit of 144 square feet, a throat area 6 by 12 feet, or of 72 square feet, an outlet opening 8.5 by 12 feet, or of 102 square feet, and operating

[1] Engineering News, vol. 64, No. 15. [2] Engineering News, Apr. 20, 1911.

under a minimum head of 36 feet. The calculated discharge of the battery is 16,600 second-feet with an assumed coefficient of 0.70 and a minimum head of 36 feet. The total capacity of the siphons and the overflow spillways at the south end and center is now estimated to be 50,000 second-feet with 5 feet of water flowing over the center spillway. Figure 1, Plate XV, shows a cut of the south-end spillway. About 300 feet below the dam proper there is a reinforced concrete hollow-type dam built to provide a stilling pool and neutralize the energy of the water falling from the three spillways.

CONCLUSIONS.

The purpose of this bulletin is to assemble, as fully as possible, all the best information known to the writer in such a way as to be of use to anyone interested in the subject. It is the intention of the writer to point out, in as brief a manner as he can, the advantages of the siphon spillway when it is desired to facilitate the escape of high flood crests, and at the same time to conserve crest length, and cost of construction and maintenance, by eliminating the use of mechanical or other energy necessary to operate partially or completely automatic spillways of other types.

It is not too broad a statement to say that the siphon is the only absolutely "foolproof" method of maintaining adequate spillway capacity without the addition of moving parts to be constantly cared for and frequently replaced, and which very often fail to operate automatically or because of the absence of an intended operator.

Furthermore, the siphon permits of (1) closer regulation of the pond level, (2) the heightening of the spillway crest and therefore additional storage capacity where each unit of height is of greater value, (3) the coming into full and efficient action almost at the moment the danger point is reached, instead of having to depend upon additional danger-producing head to increase discharge, and (4) maintaining the desired pond level by quickly ceasing to act when the danger is passed.

It is evident that having provided adequate spillway of the siphonic type in about one-half the area required for any other known automatic type, the escaping water is concentrated to a narrow jet. This allows a more economical arrangement of the channel intended to neutralize the accelerated flow and convey it to a natural drainage course.

The writer has never heard any question raised as to the possibility of damage to land or structures below the point of installation of a siphon spillway, but it has occurred to him that such possibilities do exist and that provisions may be considered to counteract such damage. The spillway of a reservoir may be called upon to discharge a large volume of water.

In cases where ordinary overflow spillways are operating, the water released and allowed to continue down the watercourse would increase and decrease with the head on the overflow, and would at no time during the discharge be greater than the volume of water contributed to the reservoir above the structure. The watercourse under such conditions would be performing its natural functions.

In the case of an ordinary siphon spillway, from the instant the siphon comes into action the volume in the channel below the structure becomes the full spillway capacity and the burden of conveying this suddenly imposed surplus may be compared to that of a similarly released flood; this for the reason that the spillway capacity is usually assumed to care for both normal and flood flow into the reservoir.

A battery of siphons may be regulated so as to bring each unit into action separately or in pairs by placing their crests and air intakes at different elevations. The regulating parts are usually placed near the high-water line of the reservoir, where flow into it results in a slow-rising water surface.

Varying the elevation of the priming parts of the different units need not utilize a range of more than from 1 to 2 feet in height, while it would regulate the outflow to conform more closely to the conditions of an ordinary overflow spillway and the volume released to the watercourse below the dam would vary with the reservoir inflow.

The lower unit should be fixed to operate at the level where it is desired to maintain the reservoir surface, and the remaining units should have their crests and air intakes set to operate at slightly higher elevations—still maintaining a safe freeboard above the highest air vent.

The writer is of the opinion that this practice has been followed on several of the larger installations, but for the purpose of regulating the pond level and not to govern the discharge to the stream below.

There are conditions where the siphon spillway is not adapted to the site or to the requirements which it is intended to serve, and its failure to perform under the improper conditions has led to condemnation of the structure as a type. For instance, one case cited in a criticism to the writer, refers to the tendency of a siphon to check the velocity of the stream near its intake and encourage the deposit of silt in front of the structure, where it was used as a regulator at the end of a canal. The design of this siphon did not take into consideration its utilization as a scouring device, but was intended only to skim the surface water and prevent the overflow of the banks of the canal. Some provisions should have been made to temporarily take care of the silt problem, since it was intended, as an ultimate development, that a power plant would be located near the site of the siphon and its installation was never intended for other than regulatory purposes. It may be stated that any other nonautomatic method of control would have presented the same objections found in this case.

Another case where the siphon was condemned as a failure proved to be its attempted use as a series of " drops " on a canal system, and the principal objection in this instance was its failure to deposit the water from the upper to the lower channel in a vertical rather than a horizontal direction, necessitating more protection to prevent scour below the structure.

It is agreed that the use of a siphon as a substitute for the ordinary overpour drop would conserve area and in addition would deliver vastly more water to the lower level per unit of cross section, but it would also produce a velocity at the outlet so much greater than the velocity developed over an overpour drop that some method of destroying the energy of the rapidly falling water must be provided. It is not evident, however, why the water should not emerge from the siphon in vertical direction as it does in an ordinary drop. It is the opinion of the writer that the use of the siphon as a drop is another case of applying the principle to a foreign use without taking the necessary precautions to provide for its primary factor—accelerated velocity.

It is hoped that in the near future the more complete study of the structure as a standard design for different conditions, forms, and efficiencies will develop data to permit of its extended use.

ACKNOWLEDGMENTS.

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THOS. H. MACDONALD, Chief

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THE FLOW OF WATER IN DREDGED DRAINAGE DITCHES.

THE RESULTS OF EXPERIMENTS TO DETERMINE THE ROUGHNESS COEFFICIENT, *n*, IN KUTTER'S FORMULA.

By C. E. Ramser, *Senior Drainage Engineer.*

CONTENTS.

INTRODUCTION.

Kutter's formula is generally accepted by engineers as being the most satisfactory formula in use for computing the flow of water in open channels. After a thorough and unbiased study of all known formulas for computing the flow in open channels, engineers of the Miami Conservancy District conclude that "Although the Kutter formula is not ideal it is the best equation available at the present time." [1] The results obtained by the use of this formula are, however, affected to such a degree by the coefficient of roughness, *n*, that the selection of the correct value for this factor is a matter of the highest importance. The series of experiments described and summarized in the following pages were made for the purpose of determining just what values of *n* properly apply to the various conditions of channel, and the endeavor has been made to present this information in the form that will be of the most practical value to engineers charged with the design of drainage channels or the computation of the discharge capacity of existing channels.

[1] The Maimi Conservancy District, Technical Reports, Part IV. "Calculation of Flow in Open Channels," by Ivan E. Houk, Assoc. M. Am. Soc. C. E.

The term *n* in Kutter's formula is a measure of all the conditions in a channel that tend to retard the flow. It is quite often regarded as simply a measure of the friction between the flowing water and the material forming the perimeter, all other conditions in the channel being disregarded. Some of the conditions that influence the value of *n* for earth channels are irregularities in the wetted perimeter, nonuniformity of cross section in size and shape, the growth of vegetation in the channel, such as grass, weeds, roots, vines, bushes and trees, and the presence of other obstructions to flow, such as logs, stumps, drift, and débris of all kinds. Various combinations of these conditions that may exist in a channel make it difficult to choose the proper value of *n* in computing the flow of an open channel or the probable flow for proposed artificial channels. The engineer who has had a wide personal observation of conditions in channels for which values of *n* have been determined is generally well qualified to choose the proper values of *n* in the design of channels. On the other hand, the engineer who has not had similar experience must depend for his choice of *n* upon views and descriptions of channels for which values of *n* have been determined by experiment. In this paper views and careful descriptions of the channels for which values of *n* were determined are presented as being the best method of making the results of practical application.

The experiments described were conducted in six different localities, namely, Lee County, Miss.; Bolivar County, Miss.; western Tennessee; western Iowa; southern North Carolina; and eastern Florida. The first four sets of experiments were made by the author. The experiments conducted in North Carolina and Florida were made by A. D. Morehouse and F. E. Staebner, respectively, both drainage engineers of the Bureau of Public Roads. All of these experiments were conducted under the direction of S. H. McCrory, chief of drainage investigations.

FIELD MEASUREMENTS.

DISCHARGE.

Particular care was taken to secure accurate discharge measurements. With few exceptions the gauging stations were located on single span bridges, so that there was no interference with the natural flow of the water. Where suitable existing bridges at desirable sections could not be found, suspension footbridges were constructed, one of which is shown in Plate I, figure 1. A cable gauging station was built on the Bogue Phalia channel in Bolivar County, Miss. (See Plate I, fig. 2.) Where the cable stations and suspension bridges were built ideal gauging sections were obtained.

Velocity measurements were made with a small Price current meter. These measurements were made at intervals of $2\frac{1}{2}$ feet across the streams for the smallest channels, 5 feet for the medium-sized channels, and 10 feet for the largest channels. At the measuring points the velocity was determined at the surface, mid-depth, and the bottom of the stream. In a few instances the velocity was measured at 0.2 and 0.8 depths. The best methods were observed in the use and care of the current meter, and it is believed that the results are entirely dependable.

Carefully made soundings were obtained during low water stages at the velocity-measuring points and wherever a decided change in the perimeter of the channel took place. As a check on these measurements, and to detect any changes due to silting or erosion, soundings were also made at the time of the velocity measurements. The depths were measured to the nearest tenth of a foot.

SLOPE OF WATER SURFACE.

The slope of the water surface was measured along the straightest and most uniform course of channel available near the gauging station, except in two instances where it was desired to ascertain the values of n for curved and crooked channels. The courses chosen were such that no tributary streams entered the channel and no decidedly abrupt changes in the bottom grade of the channel occurred along the courses, and were so located as to exclude such obstructions as logs, fallen trees, piling, and bridge piers. In one experiment, however, courses were chosen with a view to determining the influence of such obstructions upon the flow in the channels. Where the course of the channel was not limited in length by the conditions named above, the length of the course was made at least 10 times the top width of the channel. It was apparent that representative values of n could not be obtained for a channel if a long course was chosen without regard to the conditions mentioned above. For instance, during a high stage in the Bogue Hasty channel, in Bolivar County, Miss., drift accumulated at a pile trestle bridge just above the slope course, causing a fall of 0.3 foot from the upstream to the downstream side of the bridge. The actual slope of the water surface for this channel was less than 1 foot per mile, from which it is apparent that had a long slope course been chosen which included this bridge, decidedly different values of n would have been obtained. Also where long slope courses are used, incorrect values of n are often obtained, due to the entrance of surface water along the course.

In these experiments the slope of the water surface was determined by making vertical measurements from permanently set reference points to the surface of the water. These reference points were established on horizontal arms extending from vertical posts set firmly in the ground at each end of the course. Variations in water level of from 3 to 4 feet could be measured from each post, and a sufficient number of posts were set on the side slope of the channel so that all fluctuations in water surface could be measured. The elevations of the points on the arms of the posts were determined with a level to the nearest two or three thousandths of a foot and were carefully checked after every high stage in the stream to detect any possible changes due to the disturbance of the posts. The posts, however, were set in such a substantial manner, that very seldom were any changes found. The vertical measurements from the points on the arms to the water surface were made with a hook-gauge measuring rod. In some instances a stilling box arrangement was employed in connection with the hook gauge. These measurements were made either before or after the gauging was made, and often both before and after. They were made simultaneously by observers at either end of the course, or by one observer who first read at the end of the course nearer the gauging station, then at the other end, and then repeated the first measurement, the average of the first and third measurements being used. This method is based upon the assumption that the same time elapses between the first and second measurements as between the second and third measurements; hence errors due to a rising or falling stage are practically eliminated. Realizing that the accuracy of the results depended largely upon a correct determination of the slope, the utmost care was taken to secure accurate and dependable slope measurements.

CROSS SECTIONS.

The length of the slope course was carefully measured along one bank of the stream and stakes were placed at intervals of 50 or 100 feet to mark the points where the cross sections were to be taken. Where the channel was regular the cross sections were taken at intervals of 100 feet. Where the channel was irregular they were taken 50 feet apart, or at such irregular intervals as to represent as nearly as possible the true average cross section of the course. In making the cross-sectional measurements, distances across the channel were measured from the stakes to the nearest tenth of a foot. For the smaller channels, where wading was possible, elevations on the bottom and side slopes of the channels were taken with a level and rod to the nearest tenth of a foot, and were taken at intervals of 5 feet across the channel and at all points where a change in slope occurred. For the larger channels the measurements in the water section were generally taken from a boat attached to a rope stretched across the stream and fastened securely on both sides.

COMPUTATIONS.

In the experimental determination of the value of n in Kutter's formula,

$$C=\frac{41.6+\frac{1.811}{n}+\frac{0.00281}{S}}{1+\left(41.6+\frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}}$$

the coefficient C is first obtained from Chezy's formula,

$$V=C\sqrt{RS}$$

and then the value of n by solving for n in Kutter's formula. In solving Chezy's formula for C the following terms must be known:

V, the mean velocity along the slope course.

R, the mean hydraulic radius along the slope course.

S, the mean slope of the water surface along the slope course.

As has been explained, the data required for computing these values were obtained by field measurements. The mean velocity, V, was determined by dividing the discharge by the mean cross-sectional area of the channel along the slope course. The discharge was computed from the soundings and velocity measurements made at the gauging section. The method of computing the discharge was as follows: The mean velocity in the vertical at each velocity measuring point was obtained by taking one-sixth of the sum of the velocity at the surface, four times the velocity at mid depth, and the velocity at the bottom, or by taking the mean of the velocities obtained at 0.2 and 0.8 depths. The mean velocity for each section between the verticals was taken as the average of the mean velocities for the verticals on either side of the section, and the discharge for each section was obtained by multiplying the mean velocity for the section by the area of the section. The total discharge of the stream was obtained by taking the sum of the discharges for all sections across the stream.

The cross-sectional measurements were platted on cross-section paper, on a scale of 5 or 10 feet to the inch, depending upon the size of the channel. The areas and wetted perimeters for each cross section were obtained by means of a planimeter and map measurer. The mean cross-sectional area, which was used in determining the mean velocity for the course, was obtained by taking the average of all the cross-sectional areas along the course.

For some of the channels the mean hydraulic radius for the course was obtained by taking the average of all the hydraulic radii as computed for each cross section; for others it was obtained by dividing the mean cross-sectional area by the average of all the wetted perimeters as determined for each cross section along the course. There was no appreciable difference in the results obtained by the use of the two methods unless the channel was subject to large variations in cross section, in which case the first method was used.

On all of the channels the slope of the water surface was practically uniform from the upper to the lower ends of the slope courses, and the differences in the velocities at the upper and lower ends of the courses were so small that the application of a correction for the difference in velocity heads was found to be unnecessary, so far as the practical value of the results was concerned.

In calculating values of *n*, the values of *V*, *R*, and *S* were first determined as explained in the foregoing, C was then computed by Chezy's formula, and with *C*, *R*, and *S* known, the value of *n* was obtained from a large-scale diagram similar to, but larger than, the one bound in the treatise, "The Flow of Water in Rivers and Other Channels," by Ganguillet and Kutter, as translated by Hering and Trautwine.

TABULATED RESULTS.

In Tables 1 to 6 are given the hydraulic elements and values of C and *n* for the six different sets of experiments. In the third column is shown the average of the maximum depths as measured at each of the cross sections. At the foot of this column is shown the average maximum depth for a bankful stage of each channel, which enables the reader to estimate about what proportion of the channel is filled for each measurement. In the fourth column is given the average surface width along the slope course at the time of each measurement. With these two dimensions, the average cross-sectional area given in column 6, and the accompanying cross-sectional figures for each channel, a good idea can be obtained as to the shape and size of the channel. The headings at the tops of the other columns in the tables are self-explanatory. On most of the channels values of *n* were determined for several stages ranging from low to high.

Attention is called to the specially interesting features of some of the experiments. For instance, values of *n* for Old Town Creek, Table 1, were obtained before and after clearing, in order to show the effect upon *n* as produced by the presence of growth in the channel.

On the South Forked Deer River at Campbell's levee, near Jackson, Tenn., experiments were conducted to determine the relative values of *n* for three consecutive courses of channel: the first, an old straight course of the river channel; the second, an old crooked course of the river channel; and the third, a course of an irregularly dredged channel. The results which are given in Table 3, show a remarkable difference in the values of *n* obtained for the three different conditions of channel.

In the results of the Iowa experiments (Table 4) attention is called to the unusually low values of *n* obtained for earth channels. These low values, which were obtained for Boyer River and Allen and Willow Creeks, were due, no doubt, to the smoothing up of irregularities by silting and to the lubricating effect of silty mud deposited on the bottom and side slopes of the channels. The increase in the value of *n*, due to a caving bank covered with a heavy growth, is shown by the experiments made on the Little Sioux River cut-off channel before and after the caving took place.

The increase in the value of n, due to the growth of grass in channels, is shown by the results of the experiments made in North Carolina (Table 5). These experiments were made during the winter and the following summer, before and after the growth of grass in the channels.

DESCRIPTION OF CHANNELS.

At the right-hand side of each of the Tables 1 to 6 is given a complete description of the drainage channel. These detailed descriptions, supplemented by the views of the channels shown in the plates, are intended to assist the engineer in the proper choice of n for his particular use. Under the description of channels are included the factors or conditions that influence the flow of water in a channel. These factors are described under the following headings: Course, cross section, side slopes, bottom, soil, and condition. Also the approximate date when the channel was constructed is given, from which can be determined the age of the channel at the time the experiments were made.

COURSE.

The length and alignment of the course of channel are discussed under this heading. Where the length of the course is unduly short, the probability of error in the slope measurements is somewhat greater than where it is comparatively long. It was impossible in many instances, other governing factors being duly considered, to follow the general rule adopted, namely, that the length of the slope course should be at least 10 times the top width of the channel. With the exception of two courses of channels, the alignment of the slope courses was practically straight. These exceptions consisted of a bend in the Sugar Creek channel and of several irregular crooks in the old river channel at Campbell's levee, near Jackson, Tenn. (Table 3).

CROSS SECTION.

Under this heading variations in the shape of the cross section along the courses are noted, and the reader is referred to figures 2, 4, 6, 8, 10, and 12, which show the per cent variation from the average cross-sectional area for all cross sections along the slope courses. In most cases this per cent variation is shown for low, medium, and high stages. From these figures an idea can be obtained as to the progressive changes in size of the channel along the courses and whether these changes are gradual or abrupt. For instance, in figure 2 *A*, it is seen that the per cent variations are much larger and the changes in size of the channel along the course are much more abrupt for the low than for the high stage, which accounts largely for the higher values of n obtained for the low stages as recorded in Table 1.

It was found that abrupt changes in the size of a channel that are repeated at short intervals are often alone responsible for the high values of *n* obtained.

Figures 1, 3, 5, 7, 9, and 11 show the average cross sections for all of the channels. From these a general idea can be obtained as to the size and shape of the various channels.

SIDE SLOPES AND BOTTOM.

Irregularities in the perimeter of the channel are discussed under the two headings, side slopes and bottom, for the reason that the bottom alone is often the chief retarding factor during low stages. Irregularities in the perimeters of channels have a very decided effect upon the value of *n*. For instance, irregularities in the side slopes of the South Forked Deer River near Jackson, Tenn., were largely responsible for the higher values of *n* obtained for this course than were obtained for the same channel near Roberts, Tenn., where the side slopes were much more regular (Table 3). The irregularities in the channel at Jackson were due to rough finishing work with the dredge at the time of construction. To smoothness of perimeter may be attributed in part the low values of *n* obtained for the Allen and Willow Creek channels in western Iowa (Table 4).

SOIL.

Under this heading descriptions of the different types of soils found in the various channels are given. However, no noticeable difference in the retarding effect of the different soils was detected. All of the soils are of an alluvial nature, the bottoms through which the ditches were dug having been built up by deposits of silt brought down from the hills during heavy rains.

CONDITION.

An effort has been made to describe accurately the condition of the channels at the time the measurements were made. Mention is made of all sorts of growth, obstructions, and débris—factors which are in many instances responsible for the high values of *n* obtained. The pronounced effect of vegetation, such as grass, in a channel is clearly shown by the experiments made on three of the channels in North Carolina (Table 5), of the effect of small growth, such as weeds, bushes, and saplings by the experiments on Old Town Creek (Table 1), and of the effect of large obstructions, such as logs, fallen trees, and débris by the experiments on the South Forked Deer River at Campbell's levee, near Jackson, Tenn. (Table 3). Whether or not much erosion has taken place in the channel is also mentioned under this heading.

B. P. R.-D2627.

FIG. 1.—TYPICAL SUSPENSION FOOTBRIDGE GAGING STATION, MUD CREEK, LEE COUNTY, MISS.

B. P. R.-D74

FIG. 2.—CABLE GAGING STATION ON THE BOGUE PHALIA CHANNEL, NEAR HELM, MISS.

B. P. R—D2517

FIG. 1.—SLOPE COURSE OF OLD TOWN CREEK DREDGED CHANNEL, NEAR TUPELO, MISS. BEFORE CLEARING, 1913. (SEE TABLE NO. 1.)

B. P. R.—D2516

FIG. 2.—SAME VIEW AS ABOVE, AFTER CLEARING, 1914.

WHEN CONSTRUCTED.

The age of the channel at the time the experiments were made may be obtained by referring to this heading and to column 2; the former shows approximately when the channel was constructed and the latter the date when the experiments were made. The time elapsed since the construction of a dredged channel is to some extent a measure of the condition of the channel as regards growth and other obstructions to flow, except where the channel has been carefully maintained. It is also a measure of the probable extent of erosion or silting that has occurred in the channel since construction. The growth of vegetation in a channel checks erosion and promotes silting, but on the other hand active erosion in a channel checks and often entirely prevents the growth of vegetation.

Low values of n are generally found for properly finished, newly dredged channels of uniform cross section, as was the case for Mud Creek (Table 1) and South Forked Deer River, near Roberts, Tenn. (Table 3). The effect of erosion on such a channel is to make it more irregular and thereby to increase the value of n. However, after a certain amount of erosion has taken place it does not necessarily follow that further erosion will tend to increase the irregularity of the channel, as may be seen from the results obtained for the North Forked Deer River near Trenton, Tenn. (Table 3).

ACCURACY OF RESULTS.

With few exceptions there are no reasons to suspect inaccuracies in the result of these experiments. The gauging sections and slope courses were so selected as to remove as far as possible the probability of large errors in the field measurements. In some instances, which will be mentioned under the separate discussion of each channel, favorable sites for gauging stations and slope courses were not obtained. Where no mention is made as to the reliability of the results, it may be inferred that the results obtained are entirely reliable. Comparatively speaking, the most accurate results were obtained for the high stages in the various channels, since there was a greater probability of error in the gaugings and cross-sectional measurements for the lower stages.

DESCRIPTION OF EXPERIMENTS.

A description of the six sets of experiments and a discussion of the results obtained are given in the following pages.

EXPERIMENTS IN LEE COUNTY, MISS.

Experiments were conducted on five dredged channels in Lee County, Miss., namely: Old Town Creek, Mud Creek, Twenty Mile Creek, Connewah Creek, and Chawappah Creeks (see Table 1).

TABLE 1.—*Results of experiments made in Lee County, Miss.*

OLD TOWN CREEK DREDGED CHANNEL NEAR TUPELO, MISS. (BEFORE CLEARING), 1913.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
		Feet.	*Feet.*	*Second-feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
1	Mar. 4, 1913	5.4	22.9	95.3	76.2	1.25	2.90	0.000518	32.2	0.0550	*Course*, straight; 1,224 feet long. *Cross section*, slight and gradual variations in shape; for variation in size, see fig. 2 A. *Side slopes*, right side irregular, left side very irregular. *Bottom*, irregular and uneven. *Soil*, varies from black waxy clay at top to yellow clay at bottom. *Condition*, right side slope and part of bottom practically covered with small saplings, brush, and cane; occasional growths of vegetation on other side slopes. *Constructed*, Dec. 1907. (See Pl. II, fig. 1; and fig. 1 A.)
2	Mar. 3, 1913	5.8	22.0	125.7	85.5	1.47	3.12	.000513	36.8	.0490	
3	Mar. 24, 1913	6.7	25.9	179.6	108.2	1.66	3.55	.000444	41.8	.0450	
4	Mar. 21, 1913	10.8	34.9	500.7	231.8	2.16	5.30	.000388	47.6	.0433	
5	Apr. 4, 1913	11.7	35.5	579.4	261.0	2.22	5.78	.000445	43.8	.0480	
6	Feb. 27, 1913	12.6	39.0	674.0	298.2	2.26	5.95	.000452	43.5	.0490	
7	Mar. 14, 1913	13.6	45.2	823.0	341.5	2.41	6.06	.000375	50.5	.0420	
	....	[1] 13.0	......	......	......	......	......	......	......	......	

OLD TOWN CREEK DREDGED CHANNEL NEAR TUPELO, MISS. (AFTER CLEARING), 1914.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
8	Mar. 5, 1914	4.0	19.5	45.0	50.0	0.90	2.28	0.000358	31.5	0.0520	Description of channel practically the same as the above, except for remarks under *Condition*. *Condition*, all brush, vegetation, and obstructions to flow were cleared from the course of channel and for 500 feet above the upper end of the course, and for the same distance below the lower end. (See Pl. II, fig. 2.)
9	Mar. 20, 1914	4.3	20.0	59.7	58.0	1.03	2.43	.000350	35.3	.0475	
10	Apr. 17, 1914	4.65	21.0	77.9	60.4	1.29	2.55	.000377	41.6	.0410	
11	Apr. 9, 1914	5.3	22.2	105.4	74.2	1.42	2.85	.000292	49.2	.0356	
12	Apr. 3, 1914	5.4	23.0	120.0	80.0	1.50	2.90	.000312	49.8	.0355	
13	Apr. 13, 1914	6.6	26.4	185.1	107.0	1.73	3.37	.000271	57.4	.0320	
14	Mar. 26, 1914	6.7	26.5	218.2	110.2	1.98	3.42	.000305	61.4	.0299	
15	Mar. 12, 1914	7.1	27.5	240.0	120.0	2.00	3.53	.000290	62.5	.0291	
16	Mar. 26, 1914	7.1	27.6	242.4	120.0	2.02	3.58	.000279	64.0	.0290	
17	.....do.......	7.4	28.0	260.4	127.0	2.05	3.69	.000267	65.3	.0286	
18	Apr. 13, 1914	8.1	29.8	310.2	142.3	2.18	3.95	.000271	66.6	.0285	
19	May 5, 1914	11.6	37.5	710.2	265.0	2.68	5.70	.000346	60.3	.0340	
20	Mar. 30, 1914	12.4	39.7	815.6	295.5	2.76	5.95	.000268	69.1	.0297	
21	May 6, 1914	12.7	41.0	882.2	307.4	2.87	6.05	.000346	62.8	.0332	
	....	[1] 13.0	......	......	......	......	......	......	......	......	

MUD CREEK DREDGED CHANNEL NEAR TUPELO, MISS.

22	Apr. 11, 1914	2.6	18.5	54.8	40.0	1.37	1.8	0.000300	59.0	0.0267	*Course*, straight; 1,194 feet long. *Cross section*, very little variation in shape; for variation in size see fig. 2 B. *Side slopes*, quite regular. *Bottom*, even and regular. *Soil*, sandy, waxlike clay. *Condition*, newly dredged channel; no vegetation or obstructions of any sort in channel. *Constructed*, January, 1913. (See Pl. III, fig. 1; and fig. 1 B.)
23	.....do.......	2.8	19.3	61.9	43.0	1.44	1.9	.000305	59.8	.0268	
24	Apr. 7, 1914	2.9	19.5	64.8	43.2	1.50	1.9	.000305	62.3	.0257	
25	Apr. 9, 1914	3.2	20.5	74.9	47.7	1.57	2.1	.000310	61.5	.0267	
26	Apr. 5, 1914	3.8	22.0	115.0	57.5	2.00	2.3	.000301	76.0	.0224	
27	Mar. 28, 1914	4.0	22.6	125.0	61.0	2.05	2.5	.000349	69.3	.0247	
28	Mar. 26, 1914	4.1	22.8	130.2	62.6	2.08	2.6	.000336	70.4	.0246	
29	.....do.......	4.9	24.7	192.7	88.0	2.19	2.9	.000321	71.8	.0247	
30	Mar. 27, 1914	4.95	24.8	199.1	88.5	2.25	2.9	.000349	70.7	.0250	
31	Apr. 8, 1914	5.0	24.9	203.4	90.0	2.26	3.0	.000340	70.8	.0251	
32	May 5, 1914	9.9	32.5	762.8	225.0	3.39	5.3	.000364	77.2	.0258	
33	Mar. 29, 1914	10.65	34.5	904.0	252.5	3.58	5.6	.000378	77.8	.0259	
34	.....do.......	10.70	34.5	914.4	254.0	3.60	5.6	.000393	76.8	.0263	
	....	[1] 11.50	....	....	....	....	....	....	....	....	

TWENTY MILE CREEK DREDGED CHANNEL NEAR BALDWYN, MISS.

35	Mar. 28, 1913	4.5	24.0	120.0	75.5	1.59	2.75	0.000194	68.9	0.0254	*Course*, straight; 324 feet long. *Cross section*, slightly abrupt variations in shape; for variation in size, see fig. 2 C. *Side slopes*, lower, quite regular; upper, quite irregular, due to caving of banks. *Bottom*, quite even and regular. *Soil*, waxy clay loam; contains some sand. *Condition*, channel practically free from vegetation; great many roots along upper part of channel; erosion very active during high stages. *Constructed*, January, 1910. (See Pl. III, fig. 2; and fig. 1 C.)
36	Mar. 27, 1913	6.4	30.8	288.1	124.7	2.31	3.60	.000382	62.3	.0298	
37	Apr. 10, 1913	12.1	40.0	1,312.8	328.2	4.00	6.50	.000800	55.5	.0380	
38	.....do.......	[1] 13.7	42.4	1,730.3	384.5	4.50	7.15	.001150	49.6	.0440	

CHAWAPPAH CREEK DREDGED CHANNEL NEAR SHANNON, MISS.

39	Feb. 5, 1913	2.8	18.7	75.0	41.0	1.83	1.95	0.000850	44.9	0.0357	*Course*, straight; 320 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 2 D. *Side slopes*, quite regular except near top and along edge of bottom. *Bottom*, quite regular. *Soil*, varies from a sandy loam at top to a waxy clay at bottom. *Condition*, very little vegetation in channel; irregularity of upper part of channel due to erosion. *Constructed*, May, 1911. (See Pl. IV, fig. 1; and fig. 1 D.)
40	Apr. 5, 1913	7.3	31.2	368.1	156.0	2.36	4.20	.000406	57.1	.0338	
41	Feb. 28, 1913	11.1	36.4	1,152.6	282.5	4.08	6.05	.000935	54.2	.0385	
	....	[1] 12.0	....	....	....	....	....	....	....	....	

COONEWAH CREEK DREDGED CHANNEL NEAR SHANNON, MISS.

42	Apr. 4, 1913	10.6	36.7	850.0	286.2	2.97	5.95	0.000620	48.9	0.0430	*Course*, straight; 450 feet long. *Cross section*, rather gradual variations in shape; for variations in size, see fig. 2 E. *Side slopes*, very irregular. *Bottom*, irregular and uneven. *Soil*, clay loam. *Condition*, some grass and other vegetation on side slopes; bottom free from growth. *Constructed*, May, 1909. (See Pl. IV, fig. 2; and fig. 1 E.)
	....	[1] 12.0	....	....	....	....	....	....	....	....	

[1] Average maximum depth at bankful stage.

OLD TOWN CREEK.

Measurements were made on this channel early in 1913 and in 1914. A straight course of 1,224 feet below the steel highway bridge, one-half mile east of Tupelo, Miss., was selected for making the measurements. The discharge measurements for 1913 were made from the highway bridge and those for 1914 from a suspension footbridge constructed near the upper end of the course. The latter gaging section was much more desirable for accurate measurements than the former one.

An experiment for determining the effect upon the flow in the channel, due to the clearing of brush and other resistances to flow, was conducted on Old Town Creek. No clearing was done for the measurements during 1913. One side slope of the channel and part of the bottom were practically covered with small saplings, brush, and cane, and were quite irregular. The other side slope was comparatively smooth and uniform. For the measurements during 1914 all brush, logs, and other obstructions were cleared from the course of the channel and for 500 feet above the upper end and for the same distance below the lower end of the slope course, so that a comparison could be made as to the relative values of n before and after clearing. The slope of the left bank was quite regular while that of the righ bank was extremely irregular, a condition due to the growth of brush causing the bank to erode unevenly. The soil in the bottom and sides of the ditch was quite hard. The views shown in Plate II give a good idea of the conditions existing in the channel before and after clearing. (See also fig. 1 A, for average cross section of the channel.)

In Table 1, measurements 1 to 21, are given the values obtained for n, together with the various observed hydraulic elements. It is obvious, from the values of n obtained before and after clearing, that the efficiency of a channel is greatly decreased by permitting the growth of vegetation in it.

During low water the uniform fall of the surface of the water was interrupted by irregularities in the bottom and sides of the channel. For such conditions the hydraulic grade throughout the section consisted of a series of comparatively steep slopes followed by flatter ones, due to the depth of water being so small that the irregularities in the channel gave rise to quite appreciable variations in area of cross section from point to point, thus causing variations in velocity and in the hydraulic grade (see fig. 2 A). As a result the values of n obtained for low water conditions are high. The total loss of head throughout the course under such conditions is the sum of the loss due to the roughness of the wetted perimeter and the quite appreciable losses in shock and eddies that occur where the hydraulic gradient changes from a steeper to a flatter slope and where the cross section

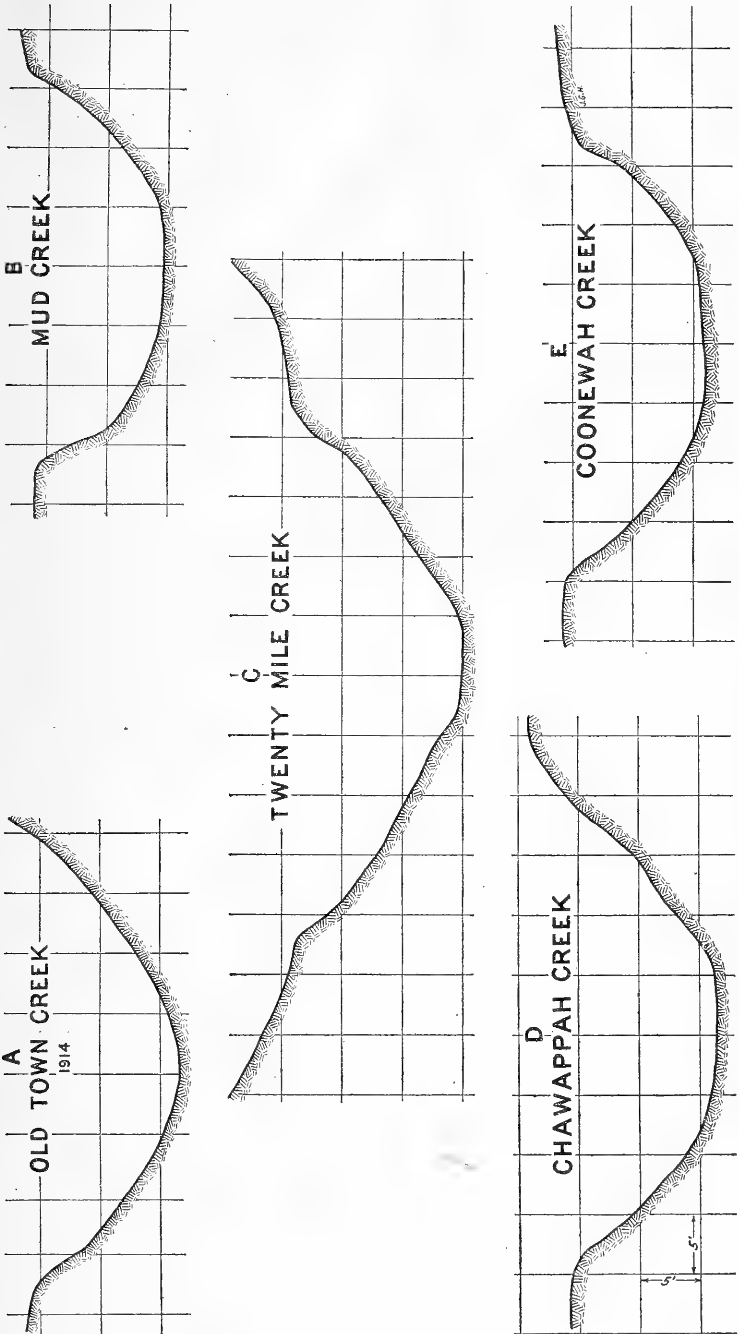

FIG. 1.—Average cross sections of channels for experiments in Lee County, Miss.

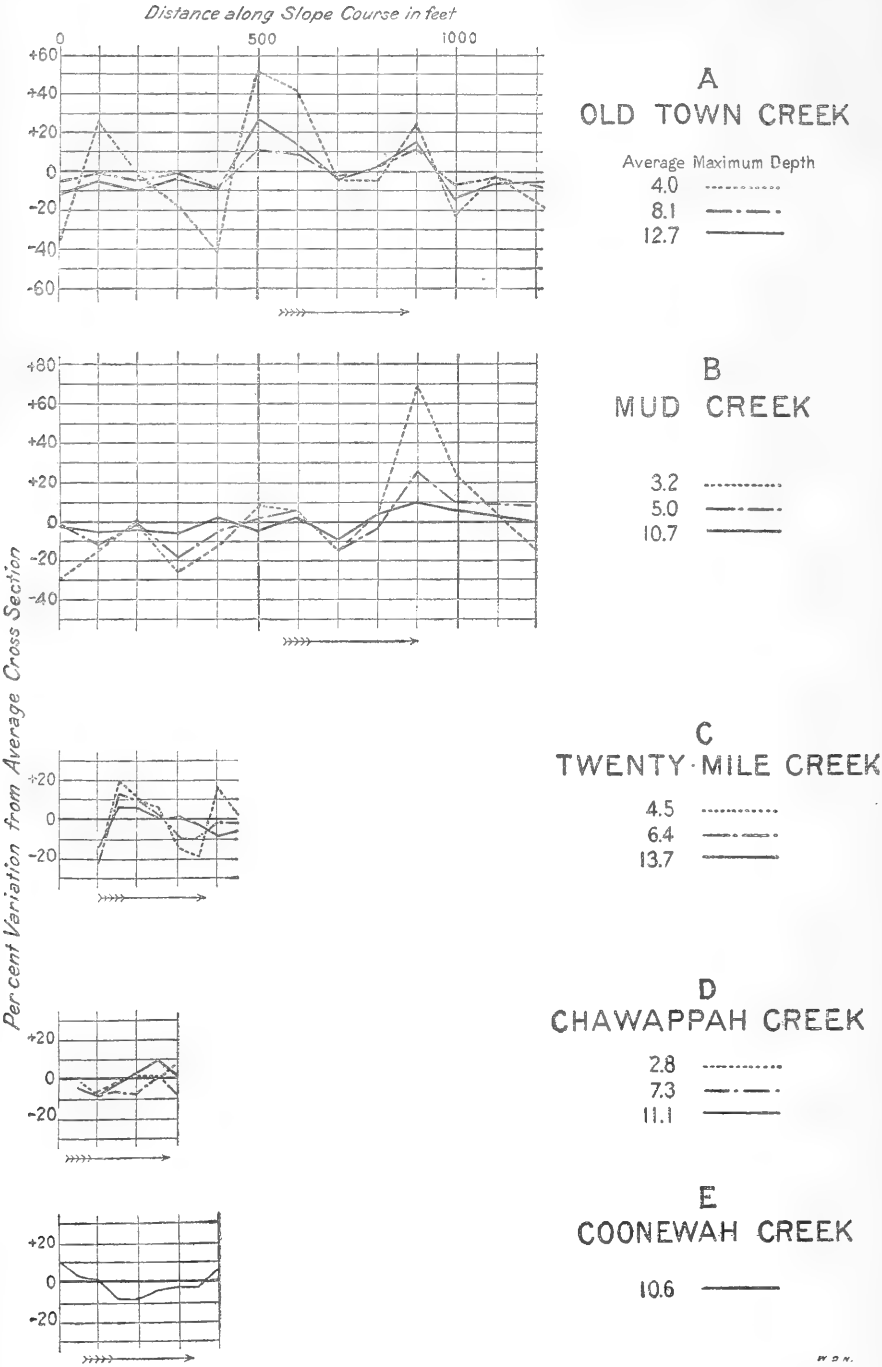

FIG. 2.—Graphs for experiments in Lee County, Miss., showing per cent variation from average cross-sectional area, for all cross sections along slope courses.

of flow changes. For low water conditions the loss in shock and eddies is quite appreciable, and as the values of n were obtained by directly measuring this total loss of head throughout the course these values would be necessarily large. The table shows that for such conditions the value of n decreases as the depth increases. This would be expected, for as the depth increases the second factor mentioned above becomes comparatively smaller, and the total loss of head thus becomes to a greater extent due to roughness of wetted perimeter and to a less extent due to the influence of eddies and shock.

In measurement No. 9, Table 1, for $n=0.0475$ the discharge is 60 second-feet; that for $n=0.030$,[1] and the same hydraulic elements, is 96 second-feet. $\frac{96-60}{60}\times 100=60$ per cent. That is, the capacity of the lower part of the channel for low water could be increased 60 per cent by eliminating irregularities in the bottom slope and abrupt changes in cross section. As will be seen later, the bottom slope and cross section of Mud Creek are practically free from irregularities, and the values of n do not vary much from low to high-water flow.

MUD CREEK.

Measurements were made on this channel during the early part of the year 1914. For the slope measurements a straight course 1,194 feet long was selected above the highway bridge about 1 mile east of Tupelo. A suspension footbridge was constructed at a site where conditions were ideal for making accurate current meter measurements.

A good idea of the condition and regularity of the channel can be obtained from Plate III, figure 1. Although in the same valley, the soil is decidedly different from that found in Old Town Creek. This part of the bottom land is made up of sediment carried from the eastern part of the Mud Creek watershed, where the soil contains considerable sand. The soil in the channel is a sandy, waxlike clay that erodes very easily. This was a comparatively new channel at the time of these experiments, the ditch having been finished in January, 1913; and, although it had eroded to some extent, it had retained its original uniform slope and comparatively uniform cross-sectional area (see figs. 1 *B*, and 2 *B*).

In Table 1, measurements 22 to 34, are shown the various hydraulic elements of Mud Creek as computed from field measurements, and the values of n obtained. That for all stages of Mud Creek is about 0.025, while that obtained for the higher stages in Old Town Creek, after clearing, is about 0.030. The lower value of n as obtained for Mud Creek can readily be ascribed to the facts that this is a more

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[1] See measurements 22–26, Table 1.

recently constructed channel and that the bottom slope and cross-sectional area are more uniform throughout the course than for Old Town Creek.

TWENTY-MILE CREEK.

The slope course on Twenty-Mile Creek was rather short, being 324 feet in length, and was located below the highway bridge 1 mile east of Baldwyn, Miss. (see Pl. III, fig. 2; and figs. 1 *C*, and 2 *C*). The lower part of the channel was quite smooth and regular, but the upper part and edge of bank were irregular. The channel is eroding rapidly, and many stumps along the banks have been undermined and fallen into the channel. Table 1 shows the hydraulic elements and the values of n obtained for Twenty-Mile Creek. The value of n increases as the stage increases, due no doubt to the irregularities in the wetted perimeter for the higher stages. The soil in the channel is a waxy clay loam, and in some parts of the channel contains considerable sand.

CHAWAPPAH CREEK.

Slope measurements for Chawappah Creek were made on a rather short course (320 feet long) between the highway and railroad bridge, one-half mile south of Shannon, Miss. The gauging section was located at the highway bridge. The view of Chawappah Creek for low water (Pl. IV, fig. 1), shows very well the condition of the channel. The soil varies from a sandy loam to a waxy clay, and the sides and bottom were quite hard. The channel is eroding very rapidly, which is partly the cause of the turbulent water surface and the resulting comparatively high values of n. The average value obtained for n was about 0.035 (see figs. 1 *D*, and 2 *D*).

COONEWAH CREEK.

Only one observation for slope was made on Coonewah Creek. The value computed for n was 0.0430. Plate IV, figure 2, shows the course on which the slope was measured and the condition of the channel. The soil is quite similar to that found on Chawappah Creek, but erosion has not been as active as on the latter (see figs. 1 *E*, and 2 *E*).

DISCUSSION OF LEE COUNTY EXPERIMENTS.

Of the experiments made in Lee County, Miss., the results obtained from those on Old Town and Mud Creeks are the most reliable. It appears that for conditions of flow the value of n for channels similar to Mud Creek is 0.025, which means that the bottom and sides should be fairly regular and free from any form of obstruction to flow, and the slope and cross-sectional area practically uniform. These conditions generally obtain only in new ditches, and it would therefore not be wise to use a coefficient as low as 0.025 in the design of channels, since the efficiency of a channel generally decreases with age, as

B. P. R.—D1645

FIG. 1.—SLOPE COURSE OF MUD CREEK DREDGED CHANNEL, NEAR TUPELO, MISS., 1913. (SEE TABLE NO. 1.)

B. P. R.—D1650

FIG. 2.—SLOPE COURSE OF TWENTY MILE CREEK DREDGED CHANNEL, NEAR BALDWYN, MISS., 1913. (SEE TABLE NO. 1.)

B. P. R.—D1638

FIG. 1.—SLOPE COURSE OF CHAWAPPAH CREEK DREDGED CHANNEL, NEAR SHANNON, MISS., 1913. (SEE TABLE NO. 1.)

B. P. R.—D1634

FIG. 2.—SLOPE COURSE OF COONEWAH CREEK DREDGED CHANNEL, NEAR SHANNON, MISS., 1913. (SEE TABLE NO. 1.)

B. P. R.—D481

FIG. 1.—SLOPE COURSE OF BOGUE PHALIA DREDGED CHANNEL, NEAR HELM, MISS., 1915. (SEE TABLE NO. 2.)

B. P. R.—D3066

FIG. 2.—SLOPE COURSE OF BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1915. (SEE TABLE NO. 2.)

B. P. R.—D409

FIG. 1.—SLOPE COURSE OF PECAN BAYOU DREDGED CHANNEL, NEAR SHAW, MISS., 1915. (SEE TABLE NO. 2.)

B. P. R.—D412

FIG. 2.—SLOPE COURSE OF WEST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1915. (SEE TABLE NO. 2.)

is shown by the experiments on Old Town Creek. It is believed that if the ditches are kept in good order the value of n can be maintained at approximately 0.030 for this section of country. If this value of n is to be maintained systematic maintenance work from the time the ditch is first constructed is necessary.

EXPERIMENTS IN BOLIVAR COUNTY, MISS.

The experiments in Bolivar County, Miss., were made on the following streams: Bogue Phalia, Bogue Hasty, Pecan Bayou, West Bogue Hasty, and East Bogue Hasty.

BOGUE PHALIA.

The conditions for the accurate discharge and slope measurements on this channel were ideal. A straight course of practically uniform cross section was selected for slope measurements, about half a mile above the Yazoo & Mississippi Valley Railroad bridge, 2 miles from Helm. The length of the course was 1,003 feet. The gauging station was located near the lower end of the course, and the velocity measurements were made from a movable car suspended from a steel cable which was stretched across the stream at right angles to the direction of flow and supported by upright poles on either bank (Plate I, fig. 2).

The left side slope of Bogue Phalia, along the course, was quite regular while the right side was subject to caving and was only fairly regular. The channel was very smooth for low stages and of uniform section for all stages (fig. 4 A). Very little vegetation of any sort was found in the channel (Plate V, fig. 1; and fig. 3 A). The soil in the lower part of the channel is sandy. The soil in the upper part is a clay loam of close texture and is quite susceptible to caving, particularly when wet.

The slope was indeed an extremely variable quantity. No two measurements of slope were found to be the same, due to the backwater conditions. The greatest slope was found for the lowest stage, and the others varied according to the effect of backwater at the time that measurements were made.

The principal hydraulic elements of the channel and the values of C and n obtained therefrom are shown in Table 2. Little variation was found in the values of C, and the values of n were found to vary from 0.0223 for the lowest stage to 0.0313 for the next to the highest stage. As would be expected, the values of n were found to be low for the lower stages, where the channel was quite smooth and uniform in section, and higher for the higher stages, where a greater resistance was offered to flow, by the rougher and more irregular sides of the channel. On the whole, it can be said that this channel was in excellent shape, a fact which is substantiated by the comparatively low values of n obtained.

TABLE 2.—*Results of experiments made in Bolivar County, Miss.*

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
	BOGUE PHALIA DREDGED CHANNEL, NEAR HELM, MISS.										
		Feet.	*Feet.*	*Second-feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
1	Jan. 14, 1915	4.20	57.5	468.5	192.0	2.44	3.11	0.000297	80.2	0.0223	*Course*, straight; 1,003 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 4 A. *Side slopes*, left side, quite regular; right side, fairly regular. *Bottom*, smooth and even. *Soil*, lower part, sandy clay loam; upper part, clay loam of close texture. *Condition*, excellent, very little vegetation of any sort; lower part of channel more uniform and regular than upper part. *Constructed*, May, 1913. (See Pl. V, fig. 1; and fig. 3 A.)
2	Feb. 13, 1915	6.20	63.3	678.4	320.0	2.12	4.61	.000159	78.3	.0247	
3	Feb. 11, 1915	8.05	68.5	906.4	440.0	2.06	5.79	.000132	74.5	.0276	
4	Feb. 10, 1915	9.45	72.5	1,102.1	535.0	2.06	6.65	.000118	73.6	.0292	
5	Feb. 9, 1915	10.85	76.5	1,363.2	640.0	2.13	7.49	.000104	76.3	.0294	
6	Jan. 27, 1915	11.10	77.3	1,635.9	657.0	2.49	7.67	.000127	79.9	.0272	
7	Feb. 8, 1915	12.20	79.8	1,650.0	750.0	2.20	8.38	.000102	75.3	.0300	
8	Feb. 2, 1915	14.80	86.1	3,142.8	970.0	3.24	10.00	.000195	73.3	.0313	
9	Feb. 4, 1915	14.80	86.1	2,929.4	970.0	3.02	10.00	.000165	74.3	.0311	
	....	[1] 18.00	....	....	....	....	....	....	....	....	
	BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS.										
10	Jan. 5, 1915	2.55	38.1	50.1	74.8	0.67	1.85	0.000152	39.9	0.0382	*Course*, straight; 1,039 feet long. *Cross section*, slight and gradual variations in shape; for variations in size, see fig. 4 B. *Side slopes*, right side very irregular and caving badly; left side quite regular. *Bottom*, rather irregular. *Soil*, upper part, dark silty loam; lower part, light yellow clay. *Condition*, upper part right side slope covered with weeds and small tree sprouts; left side slope practically free from vegetation. *Constructed*, September, 1911. (See Pl. V, fig. 2; and fig. 3 B.)
11	Jan. 20, 1915	4.05	42.3	183.6	137.0	1.34	3.01	.000183	57.1	.0312	
12	Feb. 25, 1915	5.60	47.2	275.9	209.0	1.32	4.08	.000119	59.8	.0323	
13	Feb. 22, 1915	5.75	47.3	366.8	210.8	1.74	4.10	.000166	66.7	.0285	
14	Feb. 23, 1915	7.80	53.3	650.0	314.0	2.07	5.30	.000169	69.2	.0290	
15	Jan. 25, 1915	[1] 9.50	58.2	786.6	414.0	1.90	6.31	.000157	60.4	.0353	
	PECAN BAYOU DREDGED CHANNEL, NEAR SHAW, MISS.										
16	Feb. 25, 1915	4.35	20.8	36.5	67.5	0.54	2.79	0.0000256	63.9	0.0270	*Course*, straight; 665 feet long. *Cross section*, slight and gradual variations in shape; for variation in size, see fig. 4 C. *Side slopes*, fairly regular except near the top. *Bottom*, even and regular. *Soil*, dark-colored waxy clay. *Condition*, a few weeds in channel; upper part of channel quite irregular. *Constructed*, July, 1911. (See Pl. VI, fig. 1; and fig. 3 C.)
17	Feb. 22, 1915	4.45	21.0	53.2	70.0	.76	2.85	.0000676	54.7	.0320	
18	Feb. 24, 1915	5.85	23.5	52.3	102.6	.51	3.63	.0000271	51.3	.0366	
19	.....do.......	6.35	24.3	68.1	113.5	.60	3.82	.0000271	59.0	.0326	
20	Feb. 23, 1915	[1] 6.95	25.5	110.9	127.5	.87	4.04	.0000782	49.0	.0395	

WEST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS.

21	Feb. 21, 1915	2.55	26.5	32.5	59.0	0.55	2.22	0.0001110	35.0	0.0460	*Course*, straight; 757 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 4 D. *Side slopes*, fairly regular. *Bottom*, fairly regular. *Soil*, dark-colored waxy clay. *Condition*, channel in good condition with the exception of a few weeds; sediment deposited near lower end of course caused water to stand nearly whole length of course during periods of no flow. *Constructed*, May, 1911. (See Pl. VI, fig. 2; and fig. 3 D.
22	Feb. 25, 1915	4.17	29.2	66.3	97.5	.68	2.97	.0000806	44.0	.0400	
23	Dec. 31, 1914	5.75	32.3	81.5	143.0	.57	3.79	.0000515	40.8	.0470	
24	Feb. 24, 1915	5.80	32.5	107.3	145.0	.74	3.82	.0000753	43.6	.0436	
	....	[1]8.00	....	....	....	....	....	....	....	....	

EAST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS.

25	Mar. 31, 1915	2.51	16.6	20.1	30.5	0.66	1.69	0.000231	33.4	0.0446	*Course*, straight; 502 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 4 E. *Side slopes*, slightly irregular. *Bottom*, fairly regular. *Soil*, dark-colored waxy clay. *Condition*, light growth of weeds on bottom of channel; weeds, weed stubble, and roots on side slopes. *Constructed*, July, 1911. (See Pl. VII, fig. 1; and fig. 3 E.)
26	Feb. 25, 1915	4.61	22.2	80.5	72.5	1.11	2.81	.000211	45.7	.0383	
27	Feb. 14, 1915	6.11	25.8	137.6	107.5	1.28	3.43	.000173	52.5	.0350	
28	Dec. 31, 1914	[1]6.41	26.4	149.5	115.0	1.30	3.58	.000249	43.5	.0430	

[1] Average maximum depth at bankful stage.

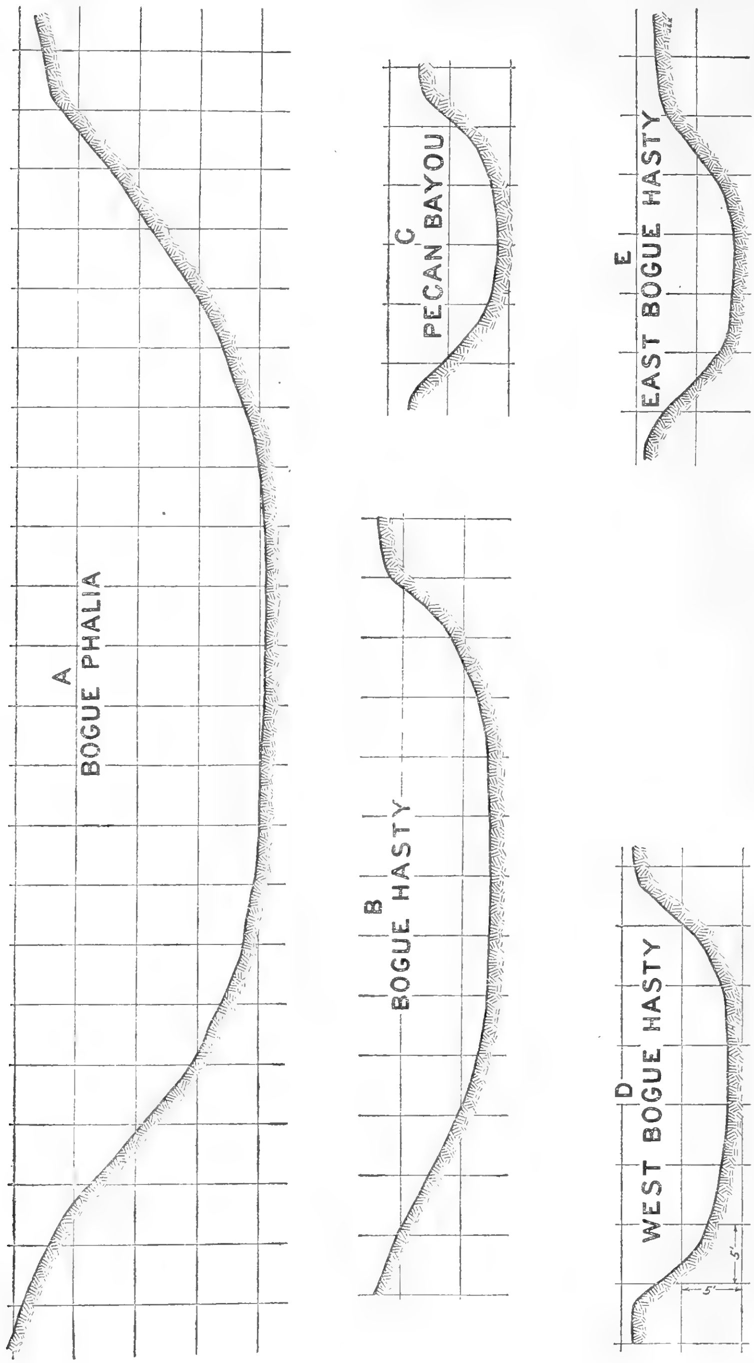


FIG. 3.—Average cross sections of channels for experiments in Bolivar County, Miss.

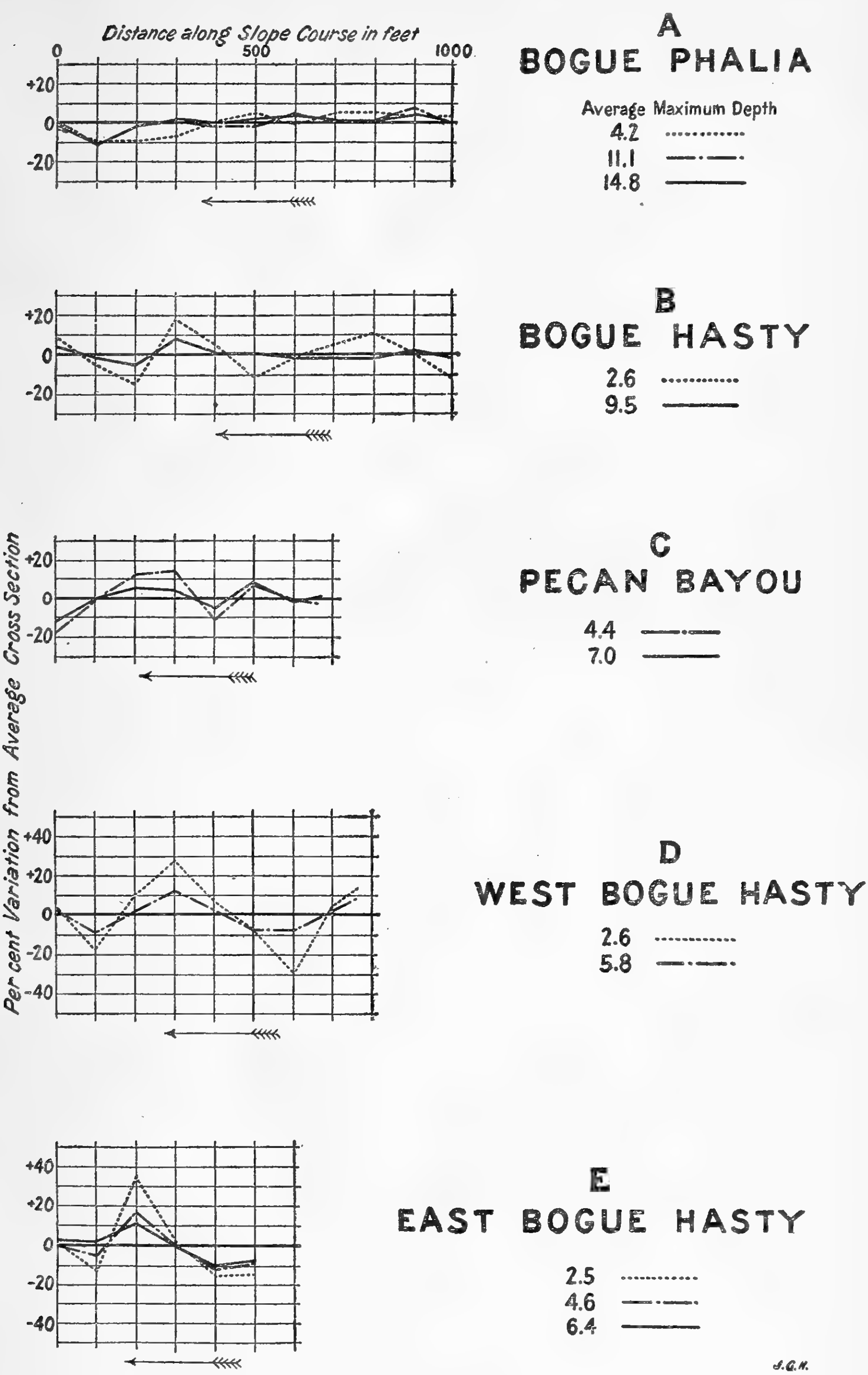


FIG. 4.—Graphs for experiments in Bolivar County, Miss., showing per cent variation from average cross-sectional area for all cross sections along slope courses.

BOGUE HASTY.

The course used for slope measurements on Bogue Hasty was 1,039 feet long. It was straight and fairly uniform (fig. 4 *B*) and no water through drain tile or surface ditches entered the channel along the course. It was located just above the highway bridge about 3 miles west of Shaw. The lower end of the course was above a slight bend in the channel and about 500 feet above the bridge. The gauging station, which consisted of a suspension footbridge (75-foot span), was placed near the lower end of the course. The conditions for both slope and discharge measurements were very good.

This channel was found not to be in as good condition as that of Bogue Phalia. The right side slope was very irregular and was caving badly. The upper part was covered with weeds and small tree sprouts. The left side slope was very regular and practically free from vegetation. (Plate V, fig. 2.) The soil in the upper part of the channel is a dark silty loam and in the lower part a light-yellow clay. It is sticky when wet and cracks and crumbles when dry (see fig. 3 *B* for average cross section of channel).

Table No. 2 shows the hydraulic elements and the values of n obtained from these experiments. The value of n (0.0382) for extreme low stage is the highest obtained for this ditch, and is probably due to the irregularities in the bed of the channel. The values of n obtained for measurements 11 to 14, inclusive, are applicable to the lower half of the channel, and they agree quite closely with those obtained for Bogue Phalia at bankful stage, the conditions of smoothness and regularity of this part of the channel being very similar to the conditions of the Bogue Phalia channel. The values of n obtained for the higher stages of the channel are considerably higher than for the lower stages. The very irregular and caving right bank would lead one to expect a larger roughness coefficient for bankful stage than for the lower half.

PECAN BAYOU.

A course 665 feet long was used for slope measurements on Pecan Bayou, located about 600 feet above the highway bridge, 5 miles directly south from Skene and about 3 miles from Shaw. The cross section of the channel at this place was quite uniform (fig. 4 *C*), and no surface water entered along the course, which was situated between two bends in the channel. A suspension footbridge for gauging purposes was placed near the lower end of the course.

Conditions on Pecan Bayou were similar to those described below for West Bogue Hasty. Much water was impounded along the course during periods of no flow. It appears that material was deposited in the channel below to impound water for the purpose of fishing. The side slopes of the channel were very regular. Some weeds were found in the channel, but not nearly as many as in the channel of East Bogue Hasty (Plate VI, fig. 1; and fig. 3 *C*). The soil is a dark-colored clay, which cracks and crumbles when dry. The slope of the water surface was found to be exceedingly small, much less than the grades designated in the original design of the channel. This was due, no doubt, to the amount of sediment deposited in the channel below the course. The values of n obtained are shown in Table 2.

WEST BOGUE HASTY.

For slope measurements on this channel a straight course 757 feet long, of quite uniform cross section at bankful stage (fig. 4 *D*), was selected, located north of the highway bridge, about 1 mile east of Litton and about 6 miles from Shaw. At the lower end of the course, stakes for slope measurements were located about 50 feet above the entrance of a lateral surface ditch. The gaugings for discharge were made from a suspension footbridge built about in the middle of the course.

The collection of drift by the bridge below the course and sedimentary deposits as a result of the drift and the entrance of a lateral ditch just above the bridge rendered this course rather unsuitable for accurate determinations of the value of n. During periods of no flow a pond of stagnant water extended nearly the whole length of the course, this being due to the sediment deposited near the bridge. The side slopes and bed of the channel were quite regular. Some weeds were found on the side slopes (Plate VI, fig. 2). The soil is similar to that found in the channel of Bogue Hasty (see fig. 3 *D* for average cross section). The results of the experiments on this ditch are shown in Table 2.

EAST BOGUE HASTY.

The course for slope measurements on East Bogue Hasty was established above the highway bridge, about 2 miles east of Litton and about 5 miles from Shaw. A stretch of 502 feet was selected, its upper end being just below a curve in the channel and the lower end just above the bridge and the entrance of a lateral ditch. The discharge measurements were made from a suspension footbridge about midway of the course. This course was rather short for accurate determinations of slope but was the straightest stretch of comparatively uniform section (fig. 4 *E*) that could be found near the lower end of the channel.

The side slopes, and in some places the bed of the channel, were covered with weeds and weed stubble, and the side slopes were slightly irregular (Plate VII, fig. 1). Practically no caving took place along the course, which fact was due, no doubt, to the vegetation covering the banks. The soil is quite similar to that in the channel of Pecan Bayou.

The values obtained for n are shown in Table 2, and, as would be expected from the condition of the channel, are even higher than those found for a bankful stage of Bogue Hasty. Some trouble was experienced during the measurements, due to drift collected at the bridge, and this may be in part responsible for the rather high values obtained for n. (See fig. 3 *E* for average cross section.)

DISCUSSION OF BOLIVAR COUNTY EXPERIMENTS.

From the foregoing description of the results obtained and the conditions existing in each of the canals it is apparent that the most dependable data were obtained for the Bogue Phalia and Bogue Hasty channels. These results show that a value of n of about 0.030, or slightly larger, applies to channels similar to the whole channel of Bogue Phalia.

The values obtained for the whole channel of Bogue Hasty, Pecan Bayou, and East and West Bogue Hasty demonstrate the effect of the conditions described upon the value of n. These values can be used as a guide in the design of drainage channels where like conditions can reasonably be expected to exist, due to the lack of maintenance of the channels or to the caving in of the banks. These data ought also to serve a useful purpose in estimating the discharge of old channels where like conditions prevail.

EXPERIMENTS IN WESTERN TENNESSEE.

These experiments were conducted during the years 1916 and 1917. Values of n were obtained for six different courses of the channel of the South Forked Deer River and for courses of the channels of the North Forked Deer River, Huggins Creek, Sugar Creek, and Cypress Creek. The author was assisted in these experiments by H. S. Andrews and A. L. Lane, junior drainage engineers of the bureau.

SOUTH FORKED DEER RIVER NEAR ROBERTS.

Gaugings of this channel were made from a single-span highway bridge about 1 mile south of Roberts. The slope course was 1,412 feet long, and was located just above the gauging station. The channel increased gradually in size from the upper to the lower end of the course, there being no abrupt changes in size or shape along the course (figs. 5 *A*, and 6 *A*). There was no vegetation nor any marked irregularities in the channel (Plate VII, fig. 2). Considerable erosion had taken place in this channel to which was largely due, no doubt, the remarkably few irregularities and the freedom from vegetation. As shown in Table 3, lower values of n were obtained for this channel than for any of the other channels in Tennessee.

B. P. R.—D410

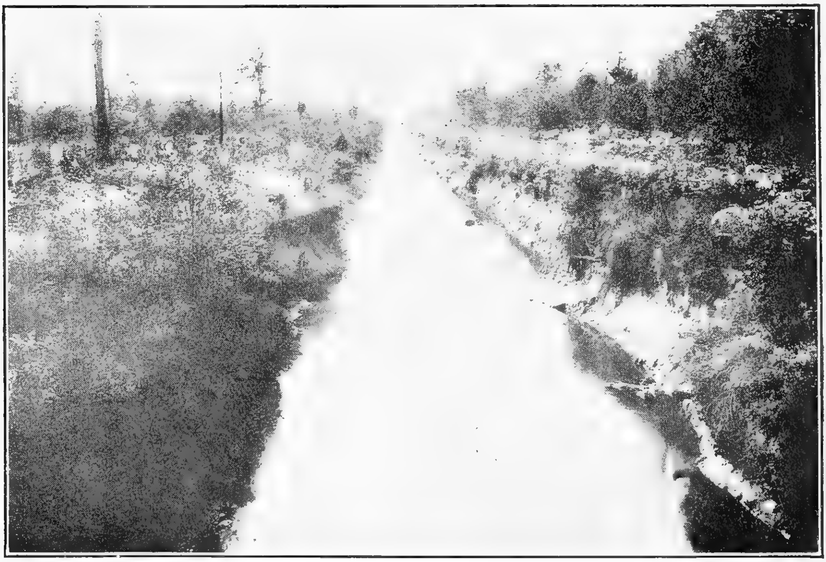
FIG. 1.—SLOPE COURSE OF EAST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1915. (SEE TABLE NO. 2.)

B. P. R.—D1285

FIG. 2.—SLOPE COURSE OF SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR ROBERTS, TENN., 1916. (SEE TABLE NO. 3.)

B. P. R.—D1287

FIG. 1.—SLOPE COURSE OF SOUTH FORKED DEER RIVER DREDGED CHANNEL AT BOLIVAR LEVEE ROAD, NEAR JACKSON, TENN., 1917. (SEE TABLE NO. 3.)



B. P. R.—D1381

FIG. 2.—SLOPE COURSE OF SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR HENDERSON, TENN., 1916. (SEE TABLE NO. 3.)

TABLE 3.—*Results of experiments made in western Tennessee.*

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ *C.*	Coefficient of roughness *n.*	Description of channel.
		Feet.	*Feet.*	*Second-feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
	SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR ROBERTS, TENN.										
1	Feb. 26, 1916	7.7	51.0	614.3	328.4	1.87	5.76	0.000094	80.5	0.0255	*Course*, straight; 1,412 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 6 A. *Side slopes*, regular and smooth. *Bottom*, even and fairly smooth. *Soil*, lower part, hard clay; upper part, clay loam. *Condition*, no vegetation or obstructions of any sort in channel. *Constructed*, October, 1915. (See Pl. VII, fig. 2; and fig. 5A.)
2	Feb. 10, 1916	8.9	52.4	798.2	390.0	2.04	6.50	.000094	82.6	.0254	
3	Mar. 29, 1916	9.5	53.4	919.4	421.8	2.18	6.84	.000096	85.2	.0252	
4	Apr. 4, 1916	10.3	54.5	1,252.1	465.0	2.70	7.28	.000124	90.0	.0240	
5	Mar. 4, 1916	10.8	55.2	1,502.6	494.0	3.04	7.55	.000166	86.0	.0248	
	....	[1] 13.0	....	....	....	....	....	....	....	....	
	SOUTH FORKED DEER RIVER DREDGED CHANNEL AT BOLIVAR ROAD, NEAR JACKSON, TENN.										
6	Dec. 13, 1916	4.3	37.6	191.6	115.9	1.66	2.89	0.000530	42.4	0.0420	*Course*, straight; 952 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 6 B. *Side slopes*, fairly regular near top, but extremely irregular and uneven near bottom. *Bottom*, very uneven and full of holes. *Soil*, heavy clay loam. *Condition*, no vegetation or obstructions in channel. *Constructed*, March, 1916. *General remarks*, high values of *n* are due to very rough and irregular condition of channel as originally dredged. The upper portion of channel is fairly regular. (See Pl. VIII, fig. 1; and fig. 5B.)
7	Dec. 20, 1916	4.95	38.4	282.2	143.0	1.97	3.33	.000555	45.8	.0402	
8	Dec. 22, 1916	5.0	38.5	290.4	147.0	1.98	3.40	.000562	45.3	.0401	
9	Mar. 31, 1917	5.1	38.6	375.0	150.0	2.50	3.46	.000694	51.2	.0362	
10	Feb. 21, 1917	5.5	39.2	433.0	166.0	2.61	3.69	.000630	54.2	.0348	
11	Jan. 17, 1917	5.8	39.6	477.0	178.0	2.68	3.87	.000642	53.8	.0349	
12	Dec. 28, 1916	9.3	51.6	1,078.0	344.0	3.13	5.69	.000477	60.2	.0341	
13	Jan. 31, 1917	9.8	54.0	1,296.0	366.0	3.55	5.83	.000534	63.6	.0322	
14	Jan. 6, 1917	10.4	57.1	1,362.0	399.4	3.41	6.10	.000436	66.1	.0310	
	....	[1] 11.0	....	....	....	....	....	....	....	....	
	SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR HENDERSON, TENN., 1916.										
15	Mar. 30, 1916	3.2	26.1	115.2	73.3	1.57	2.46	0.000257	62.4	0.0275	*Course*, straight; 624 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 6 C. *Side slopes*, slightly irregular. *Bottom*, fairly regular; uneven in places with small depressions. *Soil*, heavy clay near bottom; clay loam near top. *Condition*, practically no vegetation in channel. *Constructed*, November, 1914. (See Pl. VIII, fig. 2; and fig. 5C.)
16	Mar. 1, 1916	3.8	27.1	169.4	89.0	1.90	2.81	.000393	57.2	.0307	
17	May 16, 1916	3.9	27.4	193.2	91.5	2.11	2.87	.000305	71.3	.0249	
18	May 22, 1916	5.8	30.4	358.0	147.0	2.43	3.96	.000361	64.4	.0294	
19	May 3, 1916	6.4	31.5	434.6	168.3	2.58	4.34	.000345	66.8	.0290	
	....	[1] 9.3	....	....	....	....	....	....	....	....	

[1] Average maximum depth at bankful stage.

TABLE 3.—*Results of experiments made in western Tennessee*—Continued.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
	SOUTH FORKED DEER RIVER DREDGED CHANNEL, NEAR HENDERSON, TENN., 1917.										
		Feet.	*Feet.*	*Second-feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
20	Feb. 23, 1917	4.1	29.5	224.1	100.0	2.24	3.11	0.000532	55.0	0.0329	*Course*, same as above. *Cross section*, very little variation in shape; for variation in size, see fig. 6 D. *Condition*, channel in practically the same condition as described above, but slightly enlarged due to caving and erosion.
21	Jan. 4, 1917	4.2	29.6	240.8	103.0	2.34	3.17	.000486	59.6	.0301	
22	Jan. 20, 1917	4.3	29.7	260.9	106.0	2.46	3.24	.000435	65.6	.0277	
23	Jan. 23, 1917	5.3	31.3	333.9	138.0	2.42	3.89	.000314	69.2	.0272	
24	Feb. 15, 1917	6.1	32.7	423.9	164.0	2.58	4.34	.000313	70.0	.0275	
25	Jan. 6, 1917	[1] 9.3	36.6	953.1	278.9	3.44	6.04	.000332	76.8	.0268	
	NORTH FORKED DEER RIVER DREDGED CHANNEL, NEAR TRENTON, TENN., 1916.										
26	Feb. 4, 1916	3.6	26.5	37.6	49.2	0.76	1.93	0.000106	53.2	0.0295	*Course*, straight; 699 feet long. *Cross section*, very little variation in shape. for variation in size, see fig. 6 E. *Side slopes*, fairly regular, smooth, and steep. *Bottom*, rather irregular. *Soil*, clay loam. *Condition*, no vegetation or obstructions, banks caving badly. *Constructed*, May, 1915. (See Pl. IX, fig. 1.)
27	May 4, 1916	3.8	27.3	59.4	55.0	1.08	2.08	.000126	66.8	.0243	
28	May 15, 1916	10.7	40.3	1,167.0	316.0	3.69	6.22	.000382	75.6	.0271	
	....	[1] 11.0	....	....	....	....	....	....	....	....	
	NORTH FORKED DEER RIVER DREDGED CHANNEL, NEAR TRENTON, TENN., 1917.										
29	July 22, 1917	2.5	28.8	76.1	50.0	1.52	1.64	0.000332	65.2	0.0240	*Course*, same as above. *Cross section*, very little variation in shape; for variations in size, see fig. 6 F. *Condition*, very similar to that described above except that the size has increased greatly due to erosion and caving of banks. (See fig. 5 D for cross section.)
30	Apr. 9, 1917	3.1	30.5	125.8	69.2	1.82	2.12	.000361	65.7	.0253	
31	July 24, 1917	3.4	31.8	189.3	81.0	2.34	2.38	.000450	71.6	.0243	
32	.....do.......	3.9	33.4	246.0	97.0	2.54	2.70	.000432	74.2	.0239	
33	.....do.......	4.9	36.8	381.8	134.0	2.85	3.34	.000427	75.6	.0243	
34	July 23, 1917	8.9	47.8	1,257.5	305.0	4.12	5.54	.000468	81.0	.0249	
35	.....do.......	9.1	48.0	1,317.0	313.0	4.21	5.64	.000507	78.8	.0255	
36	.....do.......	9.2	48.2	1,324.0	318.0	4.16	5.70	.000520	76.4	.0265	
37	Jan. 5, 1917	10.5	48.8	1,513.0	367.3	4.12	6.39	.000444	77.3	.0267	
	....	[1] 11.0	....	....	....	....	....	....	....	....	

[1] Average maximum depth at bankful stage.

HUGGINS CREEK DREDGED CHANNEL, NEAR FINGER, TENN., 1916.

38	May 22, 1916	1.8	18.1	50.7	32.7	1.55	1.56	0.000855	42.5	0.0352	*Course*, straight; 914 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 6 G. *Side slopes*, very irregular. *Bottom*, rather smooth and even. *Soil*, clay loam containing some sand. *Condition*, growth of grass, weeds, and small sprouts in channel; considerable caving of banks. *Constructed* Oct., 1914. (See fig. 5 E.)
39	Feb. 9, 1916	1.85	18.3	54.1	34.0	1.60	1.62	.000923	41.4	.0369	
40	Apr. 3, 1916	2.0	19.0	63.3	36.6	1.73	1.71	.000824	46.2	.0340	
41	Feb. 1, 1916	3.0	21.0	97.4	51.0	1.91	2.16	.000875	43.9	.0371	
42	May 30, 1916	4.0	23.0	159.5	74.2	2.15	2.75	.000564	54.5	.0322	
43	......do......	[1] 6.3	31.0	371.8	140.4	2.65	3.64	.000620	55.8	.0333	

HUGGINS CREEK DREDGED CHANNEL, NEAR FINGER, TENN., 1916–17.

44	Dec. 8, 1916	2.0	18.9	49.1	35.4	1.39	1.72	0.000738	38.9	0.0398	*Course*, straight; 618 feet long; part of 1916 course. *Condition*, channel in considerably worse condition than when first series of measurements were made; more irregular and rough due to caving banks and a great deal more vegetation in channel. (See Pl. IX, fig. 2; and fig. 6 H.)
45	.....do......	2.3	19.6	63.2	40.5	1.56	1.87	.000713	42.6	.0373	
46	Dec. 28, 1916	2.55	20.1	88.2	46.0	1.92	2.06	.000888	44.8	.0366	
47	Feb. 15, 1917	2.60	20.2	88.4	47.0	1.88	2.09	.000834	45.1	.0363	
48	Dec. 28, 1916	3.0	20.8	115.2	55.9	2.06	2.34	.000835	46.6	.0362	
49	Jan. 13, 1917	3.2	21.1	123.6	58.8	2.10	2.42	.000832	46.9	.0362	
50	Mar. 3, 1917	3.5	22.2	143.6	64.3	2.23	2.55	.000877	47.2	.0365	
	....	[1] 6.3	....	....	....	....	....	....	....	....	

SUGAR CREEK DREDGED CHANNEL, NEAR HENDERSON, TENN.

51	Mar. 29, 1917	1.9	17.3	23.1	25.4	0.91	1.37	0.000729	28.8	0.0495	*Course*, 669 feet long; first half straight, last half curved. *Cross section*, very little variation in shape; for variations in size, see fig. 6 I. *Side slopes*, upper part, smooth and regular; ower part, rather rough. *Bottom*, very rough and irregular with numerous holes. *Soil*, stiff clay loam; does not wash easily. *Condition*, some roots extending from sides of channel; very little vegetation in channel. *Constructed*, Dec., 1915. *Remarks*, very rough condition of bottom is mainly responsible for high values of *n* obtained. (See Pl. X, fig. 1; and fig. 5 F.)
52	Mar. 27, 1917	2.1	17.5	29.8	29.2	1.02	1.53	.000825	28.8	.0500	
53	Jan. 4, 1917	2.6	18.2	63.6	39.9	1.59	1.96	.000970	36.5	.0437	
54	Feb. 15, 1917	3.5	19.4	148.0	57.8	2.56	2.57	.001232	45.5	.0378	
55	Dec. 28, 1917	6.3	27.2	322.0	116.0	2.78	3.41	.000936	49.2	.0373	
56	Jan. 29, 1917	6.4	27.4	376.2	117.5	3.20	3.42	.001111	51.8	.0357	
57	Jan. 22, 1917	6.6	28.2	355.2	121.9	2.92	3.44	.000920	51.9	.0356	
58	July 26, 1917	6.9	29.2	347.2	128.0	2.71	3.49	.000738	53.5	.0345	
59	Jan. 5, 1917	[1] 7.1	29.9	406.5	132.2	3.08	3.51	.000855	56.1	.0331	

CYPRESS CREEK, DREDGED CHANNEL, NEAR BETHEL SPRINGS, TENN.

60	Feb. 15, 1917	0.7	12.5	7.9	8.9	0.89	0.67	0.002080	23.9	0.0470	*Course*, straight; 308 feet long. *Cross section*, abrupt variations in shape; for variation in size, see fig. 6 J. *Side slopes*, very irregular and rough. *Bottom*, uneven; subject to variation due to sand deposits. *Soil*, clay loam. *Condition*, exposed perimeter above low water practically covered with grass and weeds. *Constructed*, December, 1915. (See Pl. X, fig. 2; and fig. 5 G.)
61	July 23, 1917	2.3	17.3	72.4	33.8	2.14	1.76	.002435	32.7	.0470	
62	.....do......	2.9	18.8	103.7	42.1	2.46	1.99	.001915	39.9	.0403	
	....	[1] 5.5	....	....	....	....	....	....	....	....	

[1] Average maximum depth at bankful stage.

TABLE 3.—*Results of experiments made in western Tennessee*—Continued.

SOUTH FORKED DEER RIVER, OLD AND DREDGED CHANNELS, AT CAMPBELLS LEVEE ROAD, NEAR JACKSON, TENN.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
	IRREGULAR DREDGED CHANNEL.										
		Feet.	*Feet.*	*Second-feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
63	Mar. 20, 1916	4.5	43.6	395.2	176.1	2.24	3.61	0.000571	49.4	0.0380	*Course*, fairly straight; 534 feet long. *Cross section*, rather gradual variations in shape; for variation in size, see fig. 6 K. *Side slopes*, very irregular. *Bottom*, very rough and uneven. *Soil*, sandy clay loam. *Condition*, very little vegetation; few obstructions in channel. *Constructed*, August, 1914 (See Pl. XI, fig. 1; and fig. 5 H.)
64	Feb. 25, 1916	6.1	46.9	545.9	249.0	2.19	4.65	.000552	43.2	.0455	
65	Mar. 29, 1916	7.3	49.8	735.7	305.0	2.41	5.33	.000452	49.2	.0410	
66	Mar. 4, 1916	7.5	50.3	715.1	315.6	2.27	5.45	.000300	56.2	.0367	
	....	[1] 13.0	....	....	....	....	....	....	....	....	
	OLD STRAIGHT RIVER CHANNEL.										
67	Mar. 20, 1916	7.0	40.0	395.2	196.2	2.01	4.44	0.000584	39.5	0.0500	*Course*, fairly straight; 497 feet long. *Cross section*, considerable variation in shape; for variation in size, see fig. 6 L. *Side slopes*, irregular. *Bottom*, irregular with deep holes. *Soil*, sandy clay loam. *Condition*, sides of channel covered with trees, roots, and vines and subject to caving; logs, branches, and other drift on bottom of channel. (See Pl. XI, fig. 2; and fig. 5 I.)
68	Feb. 25, 1916	8.0	41.7	545.9	240.2	2.27	5.09	.000734	37.2	0550	
69	Mar. 29, 1916	8.8	43.2	735.7	275.0	2.68	5.56	.001088	34.4	.0620	
70	Mar. 4, 1916	8.9	43.7	715.1	281.9	2.54	5.66	.000952	34.6	.0619	
71	Feb. 3, 1916	11.5	48.8	1,066.6	403.2	2.64	7.19	.000501	44.1	.0505	
	....	[1] 13.5	....	....	....	....	....	....	....	....	
	OLD CROOKED RIVER CHANNEL.										
72	Mar. 20, 1916	5.1	46.5	395.2	241.2	1.64	4.15	0.003773	13.1	0.1520	*Course*, very crooked, containing four distinct curves; 705 feet long at low water. *Cross section*, large variations in shape; for variation in size, see fig. 6 M. *Side slopes*, very irregular. *Bottom*, very irregular and full of holes. *Soil*, sandy clay loam. *Condition*, many roots, trees, and bushes on sides, and many logs, large trees, and other drift on bottom; trees are continually falling into channel, due to caving banks. (See Pl. XII, fig. 1; and fig. 5 J.)
73	Feb. 25, 1916	6.5	50.0	545.9	311.5	1.75	4.99	.003812	12.7	.1620	
74	Mar. 29, 1916	7.6	54.0	735.7	366.0	2.01	5.56	.003450	14.6	.1500	
75	Mar. 4, 1916	7.8	55.0	715.1	376.7	1.99	5.68	.002709	15.3	.1460	
76	Feb. 3, 1916	11.1	64.5	1,066.6	575.8	1.85	7.60	.001486	17.4	.1400	
	....	[1] 13.0	....	....	....	....	....	....	....	....	

[1] Average maximum depth at bankful stage.

SOUTH FORKED DEER RIVER NEAR JACKSON.

Discharge measurements of this channel were made from a single-span skew highway bridge on the Bolivar levee road about one-half mile from Jackson. The upper end of the slope course was located about 75 feet below the bridge and extended downstream 952 feet in a straight course. The cross-sectional area was fairly uniform for high stages, but for low stages several abrupt changes in size occurred (figs. 5 *B*, and 6 *B*). The effect of roughness and irregularities in the lower portion of the channel upon the value of n is revealed in the results obtained (Table 3). Although the channel was free from vegetation and obstructions, yet the values of n obtained are considerably higher than those obtained for the channel at Roberts. The irregularities in the channel were left at the time of construction, the bottoms and sides having never been smoothed up properly (see Plate VIII, fig. 1).

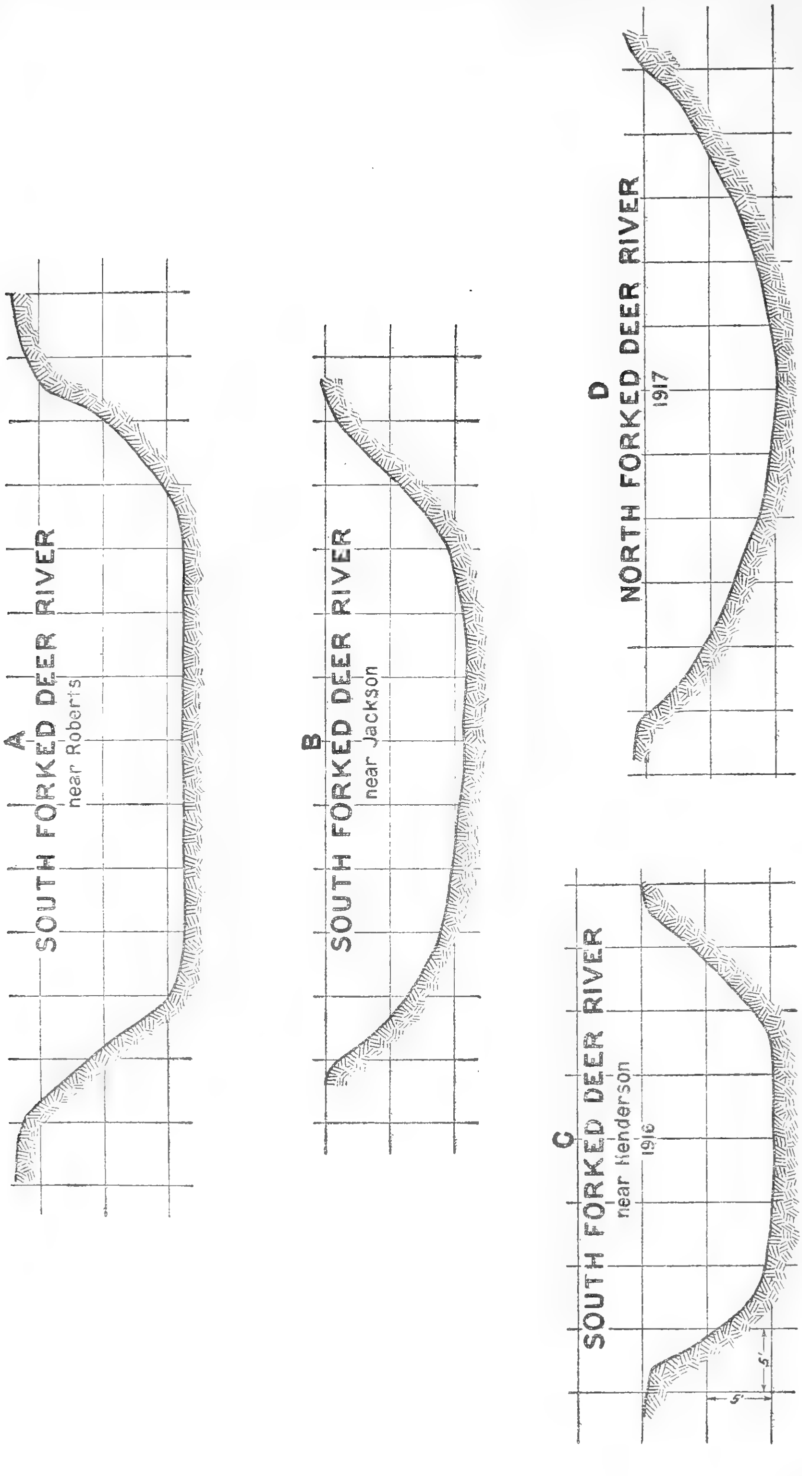
SOUTH FORKED DEER RIVER NEAR HENDERSON.

The gauging station was located on the single-span highway bridge about 1½ miles east of Henderson, Tenn. A straight course 624 feet in length, below the gauging station, was selected for slope measurements. Experiments were made on this channel during both 1916 and 1917, and there was very little difference in the channel for the two sets of experiments or in the values of n obtained for the corresponding stages (Table 3). It is believed that the results obtained are quite accurate. The channel as a whole was in very good condition. The side slopes were slightly irregular, the bottom was fairly even except for a few depressions, and there was practically no vegetation in the channel (see Plate VIII, fig. 2; and figs. 5 *C*, 6 *C*, and 6 *D*).

NORTH FORKED DEER RIVER NEAR TRENTON.

A single-span skew bridge on the Huntingdon levee road about one-half mile from Trenton was used as a gauging station. The slope course was straight and extended upstream from near the bridge for a distance of 699 feet. The variations in the cross-sectional area were quite large, but there were no abrupt changes in section for the higher stages. Owing to the fact that the size of the channel increased gradually from the upper to the lower end of the course, it is not believed that the differences in the area of the cross section had any appreciable effect upon the value of n for the course (see figs. 5 *D*, 6 *E*, and 6 *F*). There were practically no vegetation or other obstructions in the channel (Plate IX, fig. 1).

Referring to measurements 28 and 37 in Table 3, it is seen that the values of n obtained for the highest stages during 1916 and 1917 were 0.0271 and 0.0267, respectively. The increase in size of the


A
SOUTH FORKED DEER RIVER
near Roberts
B
SOUTH FORKED DEER RIVER
near Jackson
C
SOUTH FORKED DEER RIVER
near Henderson
1916
D
NORTH FORKED DEER RIVER
1917
5'
5'

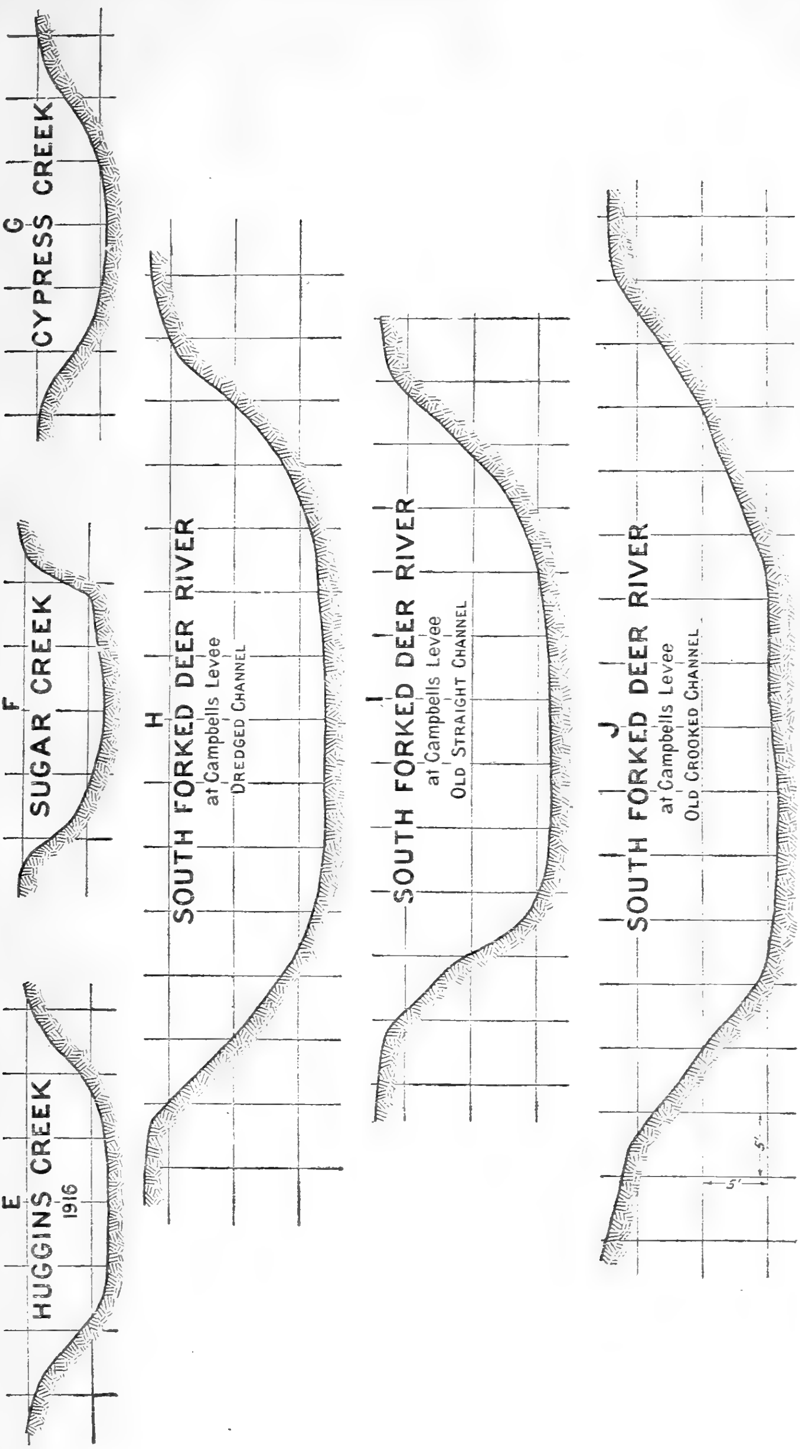


FIG. 5.—Average cross sections of channels for experiments in western Tennessee.

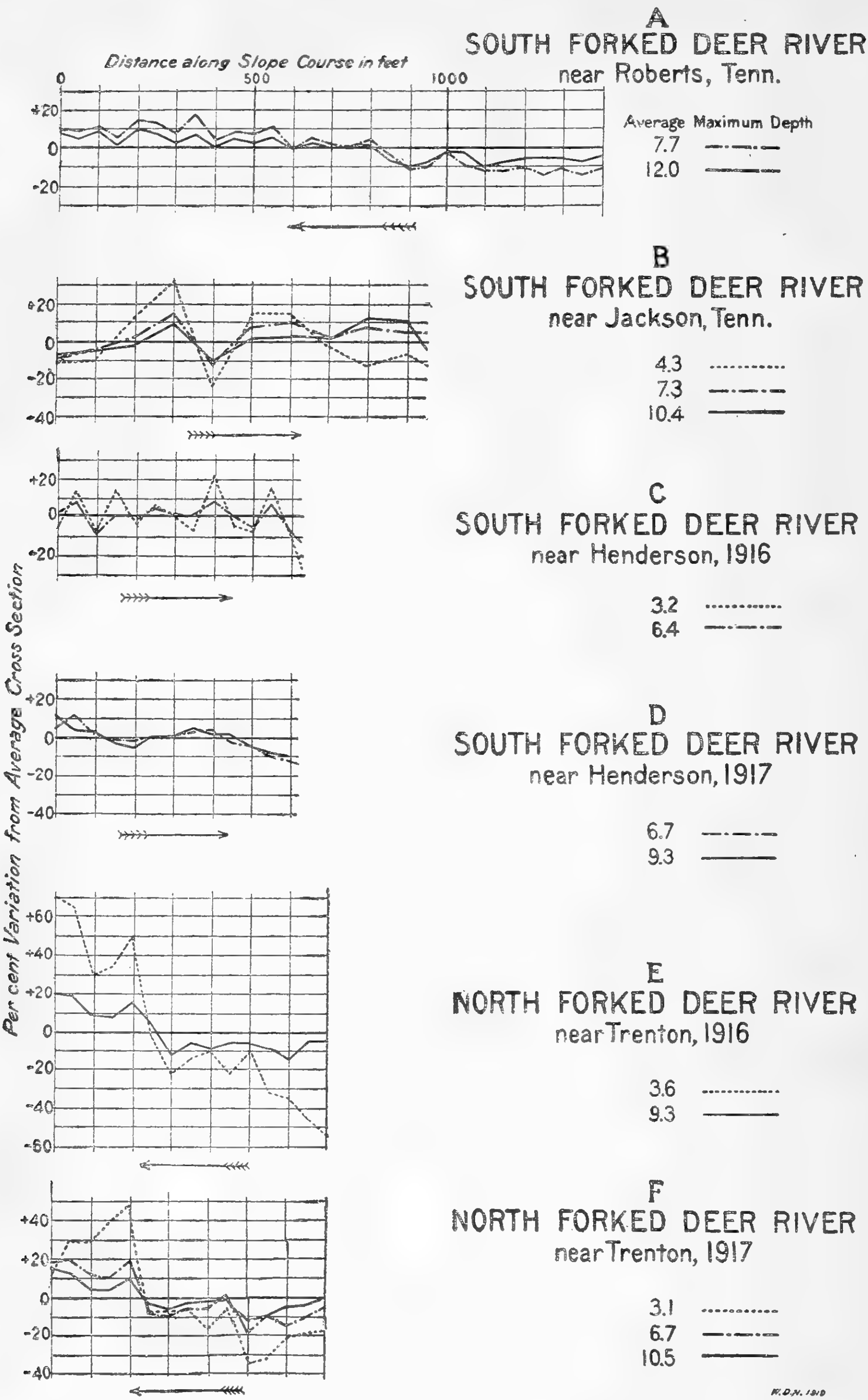


FIG. 6.—Graphs for experiments in western Tennessee, showing per cent variation

B. P. R.—D272

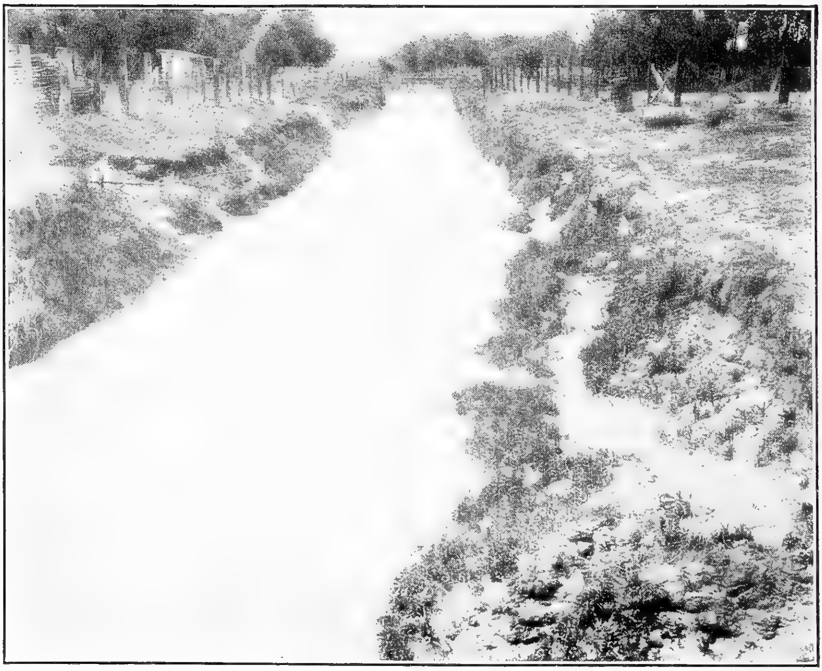
FIG. 1.—SLOPE COURSE OF NORTH FORKED DEER RIVER DREDGED CHANNEL, NEAR TRENTON, TENN., 1916. (SEE TABLE NO. 3.)

B. P. R.—D1797

FIG. 2.—SLOPE COURSE OF HUGGINS CREEK DREDGED CHANNEL, NEAR FINGER, TENN., 1917. (SEE TABLE NO. 3.)

B. P. R.—D1376

FIG. 1.—SLOPE COURSE OF SUGAR CREEK DREDGED CHANNEL, NEAR HENDERSON, TENN., 1917. (SEE TABLE NO. 3.)



B. P. R.—D1332

FIG. 2.—SLOPE COURSE OF CYPRESS CREEK DREDGED CHANNEL, NEAR BETHEL SPRINGS, TENN., 1917. (SEE TABLE NO. 3.)

B. P. R.—D269

FIG. 1.—SLOPE COURSE OF SOUTH FORKED DEER RIVER DREDGED CHANNEL AT CAMPBELL'S LEVEE, NEAR JACKSON, TENN., 1916. (SEE TABLE NO. 3.)

B. P. R.—D710

FIG. 2.—SLOPE COURSE OF SOUTH FORKED DEER RIVER (OLD STRAIGHT RIVER CHANNEL) AT CAMPBELL'S LEVEE, NEAR JACKSON, TENN., 1916. (SEE TABLE NO. 3.)

B. P. R.—D271

FIG. 1.—SLOPE COURSE OF SOUTH FORKED DEER RIVER (OLD CROOKED RIVER CHANNEL) AT CAMPBELL'S LEVEE, NEAR JACKSON, TENN., 1916. (SEE TABLE No. 3.)

B. P. R.—D1202

FIG. 2.—SLOPE COURSE OF ALLEN CREEK DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA, 1917. (SEE TABLE No. 4.)

B. P. R.—D1203

FIG. 1.—SLOPE COURSE OF WILLOW CREEK DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA, 1917. (SEE TABLE NO. 4.)

B. P. R.—D1200

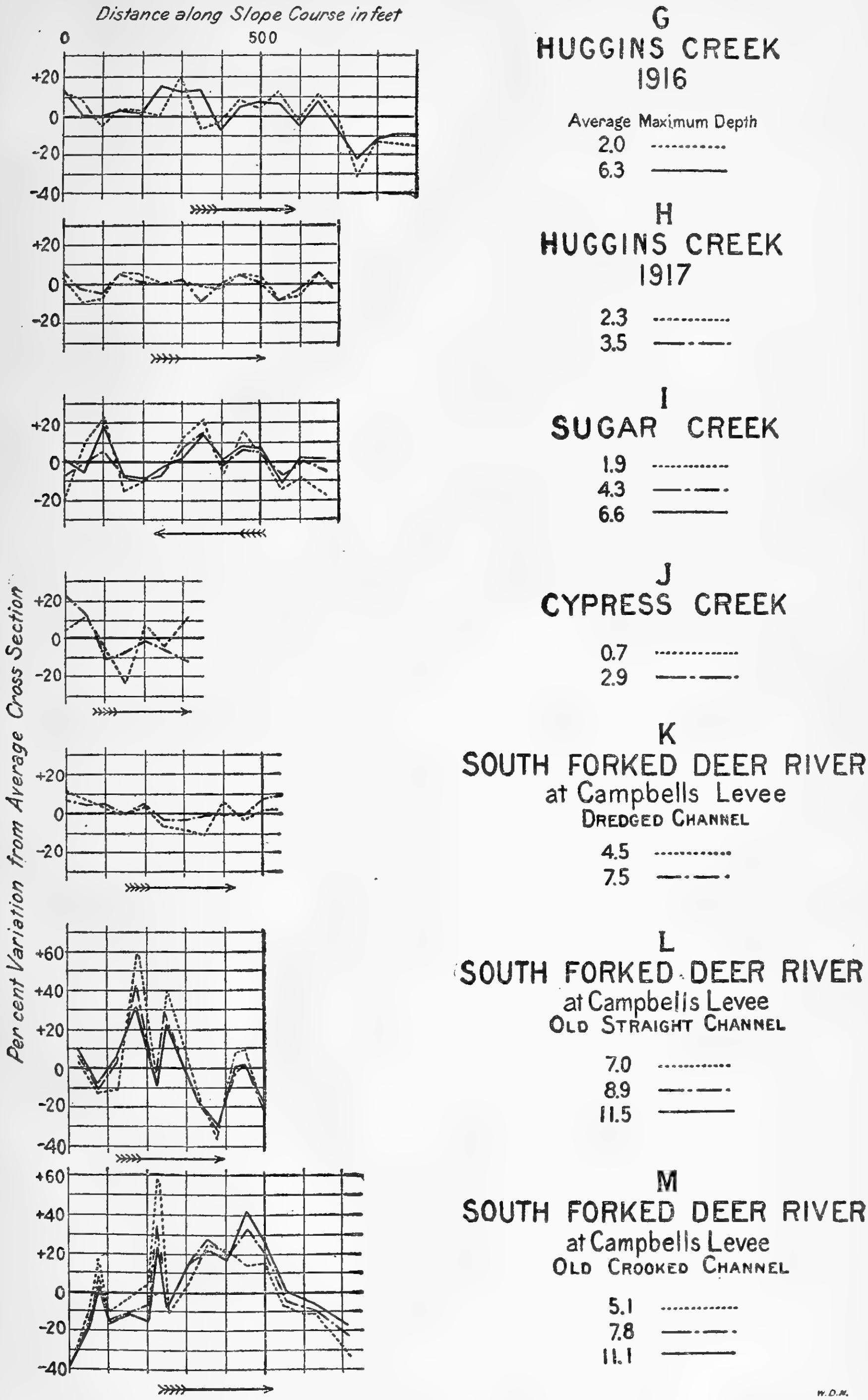
FIG. 2.—SLOPE COURSE OF BOYER RIVER DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA, 1917. (SEE TABLE NO. 4.)

B. P. R.—D1284

FIG. 1.—SLOPE COURSE OF PIGEON CREEK DREDGED CHANNEL, NEAR CRESCENT, IOWA, 1917. (SEE TABLE NO. 4.)

B. P. R.—D2420

FIG. 2.—SLOPE COURSE OF MONONA-HARRISON DREDGED CHANNEL, NEAR ONAWA, IOWA, 1916. (SEE TABLE NO. 4.)



from average cross-sectional area for all cross sections along slope courses.

channel due to erosion during the interval of time between the above measurements was 23.5 per cent, from which it is seen that the erosion of the channel in this particular instance produced practically no change in the value of *n* for the channel. The low values of *n* for the higher stages as compared with the results obtained for the other channels may be attributed to the absence of abrupt changes in cross section and to the freedom from growth and obstructions in the channel.

HUGGINS CREEK.

The Huggins Creek gauging station was located on the single-span highway bridge about 100 yards east of the Mobile & Ohio Railroad, near Finger, Tenn. The slope course was straight, extended downstream from the gauging station, and was 914 feet long for the first series of experiments and 686 feet long for the second (Plate IX, fig. 2; and figs. 5 *E*, 6 *G*, and 6 *H*).

The values obtained at Finger (Table 3, measurements 38 to 50) are fairly consistent for all stages and are rather high. This is due to the fact that irregularities and growth in the channel are quite evenly distributed from top to bottom of the channel and to large variations in cross section. This channel is rapidly deteriorating, due to caving of the banks and to growth in the channel, which fact is indicated by the higher values of *n* obtained during the second period of investigations,

SUGAR CREEK.

The gauging station for Sugar Creek was located on a single-span highway bridge a short distance above the Mobile & Ohio Railroad, and about one-half mile from Henderson. The slope course was located below the bridge and was 669 feet long, the first half of the course being straight and the last half a smooth, easy curve. There was found to be no appreciable difference in the slope as between the curved and straight portions of the slope course. Abrupt changes in the size of the channel occurred along the slope course (figs. 5 *F*, and 6 *I*), and the lower portion of the channel was rough and irregular, not having been finished up properly at the time of construction. (See Table 3 for values of *n* and Plate X, fig. 1, for view of channel.)

CYPRESS CREEK.

Gaugings of Cypress Creek were made from the single-span cattle bridge about 200 yards above the highway bridge at Bethel Springs, Tenn. This bridge was located on the slope course, close to the lower end. The slope course was straight and 308 feet in length.

Values of *n* for the high stages were not obtained for Cypress Creek. The values obtained (see Table 3, measurements 60 to 62) are high, as is the case on most of the channels at low stages, and are due to irregularities and vegetation in the channel. It is likely that a lower value of *n* would have been obtained for a bankful stage. (See Plate X, fig. 2; and figs. 5 *G*, and 6 *J*.)

SOUTH FORKED DEER RIVER AT CAMPBELL'S LEVEE ROAD.

Experiments were conducted on the river channel at the Campbell's levee road, near Jackson, to determine the values of *n* for three different but consecutive courses, viz: Old channel (straight and crooked) and new, irregular, dredged channel. The relation of these courses as to location and alignment is shown in figure 6*X*. A good comparison for the courses can be made, since the values of *n* for the different courses were computed from the same discharge measurements, made from a suspension footbridge at the upper end of the old straight course, so that any error in discharge would not materially affect the relative values of *n*. The results obtained, and a detailed description of the three different courses, are given in

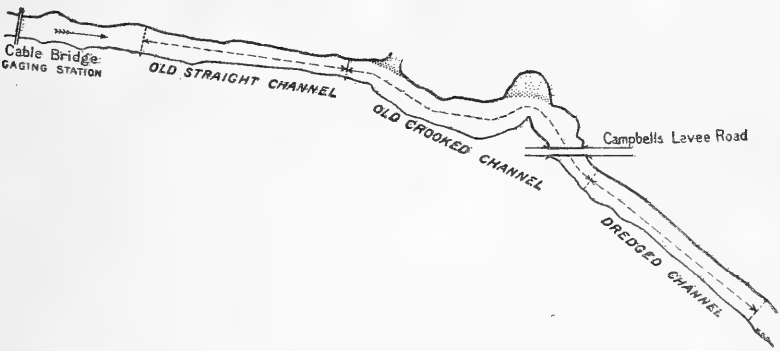


FIG. 6x.—Slope course at Campbells Levee, South Forked Deer River, near Jackson, Tenn.

Table No. 3, measurements 63 to 76 (see Plate XI and Plate XII, fig. 1, for views of the three courses). The conditions found in the two sections of the old channel are typical of those prevailing in channels in this section of the country. The dredged channel is more irregular in shape of cross section than is the usual dredged channel in this part of the country. (For cross sections and variation in size of channel along slope courses see figs. 5 *H*, 5 *I*, 5 *J*, 6 *K*, 6 *L*, and 6 *M*.)

In comparing the values of *n* obtained for the fourth measurement in each channel (Table 3, measurements 66, 70, and 75) it is seen that the values are 0.0367, 0.0619, and 0.146 for the dredged, old straight, and old crooked channels, respectively; also that the slopes required for the same discharge is more than three times as much for the old straight channel as for the dredged channel, and about nine times as much for the old crooked channel. In order to show the relative capacities for these three courses of channel, for the values of *n* given above, the following computations were made in which the slope, hydraulic radius, and cross-sectional area for measurement 66 were used.

[Cross-sectional area=315.6 square feet. Hydraulic radius=5.45 feet. Slope=0.0003.]

Channel.	n	C	Mean velocity.	Discharge.	Relative discharges.
			Ft. per sec.	*Sec. feet.*	*Per cent.*
Dredged	0.0367	56.2	2.27	715.1	100.0
Old straight	.0619	34.8	1.40	443.5	62.1
Old crooked	.1460	15.1	0.61	192.7	27.0

Results of the above computations show that for similar cross sections and slope the dredged, old straight, and old crooked channels would carry 715.1, 443.5, and 192.7 second-feet, respectively, the capacity of the old straight channel being only 62.1 per cent of that of the dredged, and of the old crooked channel only 27 per cent of the dredged. The difference in the capacities of the old straight channel and old crooked channel is not due entirely to the curves in the latter, since the accumulation of drift, trees, and logs was greater in the crooked channel. However, the difference in the condition of the two channels may be directly attributed to the presence of the curves, since there is a greater tendency for drift and other obstructions to accumulate in a crooked than in a straight course of channel.

DISCUSSION OF WESTERN TENNESSEE EXPERIMENTS.

The experiments in western Tennessee cover a greater variety of conditions in channels than do any of the other six sets, the values of n obtained ranging from 0.024 for the dredged channels near Roberts and Trenton to 0.162 for the old crooked river channel near Jackson. The results, however, do not justify the use of a coefficient as low as the first named above in the design of dredged channels, since it is not the rule that a dredged channel maintains its original efficiency. It is not believed that a value of n less than 0.030 should be used for this section of the country, and it will be noted that this statement is in agreement with the conclusions deduced for the two sets of experiments made in Mississippi. Where it is desired to compute the capacity of an existing channel, the proper value of n can be selected by a comparison of the conditions in the channel with the conditions described for the various channels for which n has been determined in these experiments.

EXPERIMENTS IN WESTERN IOWA.

Experiments in western Iowa were conducted on the following streams: Allen Creek, Willow Creek, Pigeon Creek, Boyer River, the Monona-Harrison Ditch, and Little Sioux River.

B. P. R.—D2425

FIG. 1.—SLOPE COURSE OF LITTLE SIOUX RIVER CUT-OFF DREDGED CHANNEL, NEAR TURIN, IOWA, 1916. (SEE TABLE NO. 4.)

B. P. R.—D1087

FIG. 2.—SAME VIEW AS ABOVE, 1917.

B. P. R.—D1931

FIG. 1.—SLOPE COURSE OF TURKEY BRANCH DREDGED CHANNEL NEAR PEMBROKE, N. C., 1915. (SEE TABLE NO. 5.)

B. P. R.—D1866

FIG. 2.—SLOPE COURSE OF BACK SWAMP DREDGED DITCH, NEAR LUMBERTON, N. C., 1915. (SEE TABLE NO. 5.)

TABLE 4.—*Results of experiments made in western Iowa.*

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
	ALLEN CREEK DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA.										
		Feet.	*Feet.*	*Sec. feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
1	June 4, 1917	7.1	42.3	930.8	196.2	4.74	4.30	0.0002897	134.5	0.0140	*Course*, straight; 794 feet long. *Cross section*, practically no variation in shape; for variation in size, see fig. 8 A. *Side slopes*, smooth and regular. *Bottom*, even and regular. *Soil*, heavy, dark, silty loam. *Condition*, practically no vegetation in channel; bottom covered with ½ to 1 foot of mud; sides covered with silt of slimy and slippery nature which was no doubt principally responsible for low value of *n*. *Constructed*, summer of 1916. (See Pl. XII, fig. 2; and fig. 7 A.)
2	......do........	7.15	42.4	837.1	197.4	4.24	4.32	.0002392	132.7	.0142	
	....	[1] 8.00	....	....	....	....	....	....	....	....	
	WILLOW CREEK DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA.										
3	June 4, 1917	6.3	45.5	897.6	216.1	4.15	4.46	0.0002023	138.3	0.0137	*Course*, straight; 1,004 feet long. *Cross section*, practically no variation in shape; for variation in size, see fig. 8 B. *Side slopes*, left side slope smooth and even; other side somewhat uneven and irregular. *Bottom*, even and regular. *Soil*, heavy, dark, silty loam. *Condition*, very little vegetation in channel; presence of silt and mud practically the same as described for Allen Creek. *Constructed*, summer of 1916. (See Pl. XIII, fig. 1; and fig. 7 B.)
4	June 6, 1917	6.4	46.0	813.6	220.3	3.69	4.49	.0001694	133.7	.0143	
5	June 4, 1917	7.4	48.5	1,195.0	273.5	4.37	5.17	.0001624	150.7	.0128	
	....	[1] 9.0	....	....	....	....	....	....	....	....	
	BOYER RIVER DREDGED CHANNEL, NEAR MISSOURI VALLEY, IOWA.										
6	June 8, 1917	5.3	64.0	904.5	288.0	3.14	4.29	0.0003340	83.1	0.0230	*Course*, straight; 868 feet long. *Cross section*, considerable but gradual variations in shape; for variation in size; see fig. 8 C. *Side slopes*, fairly regular. *Bottom*, somewhat uneven and irregular. *Soil*, upper part, dark silty loam; lower part, hard yellow clay. *Condition*, practically no vegetation in channel; bottom and sides coated with layer of slippery silt. *Constructed*, 1910. (See Pl. XIII, fig. 2; and fig. 7 C.)
7	June 7, 1917	7.0	69.0	1,438.6	410.9	3.50	5.58	.0002525	93.3	.0214	
8	June 6, 1917	10.5	76.0	2,707.4	663.7	4.08	7.80	.0001883	106.5	.0197	
9	June 4, 1917	11.7	79.0	3,213.4	755.5	4.25	8.59	.0001278	128.3	.0165	
10	.....do........	12.2	80.0	3,756.0	799.0	4.70	8.99	.0001255	139.9	.0151	
	....	[1] 15.0	....	....	....	....	....	....	....	....	
	PIGEON CREEK DREDGED CHANNEL, NEAR CRESCENT, IOWA.										
11	June 6, 1917	11.7	48.5	1,685.1	329.8	5.11	6.18	0.000642	81.1	0.0249	*Course*, straight; 858 feet long. *Cross section*, slight variation in shape; for variation in size, see fig. 8 D. *Side slopes*, left side fairly regular; right side rough and irregular. *Bottom*, slightly irregular. *Soil*, heavy, dark silty loam. *Condition*, very little vegetation in channel; bottom covered with ½ to 1 foot of mud; sides coated with slippery silt. *Constructed* 1907. (See Pl. XIV, fig. 1; and fig. 7 D.)
	....	[1] 12.0	....	....	....	....	....	....	....	....	
12	June 6, 1917	12.4	53.8	2,047.1	363.7	5.63	6.12	.000621	91.4	.0220	

[1] Average maximum depth at bankful stage.

TABLE 4.—*Results of experiments made in western Iowa*—Continued.

MONONA-HARRISON DREDGED CHANNEL, NEAR ONAWA, IOWA, 1916.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
		Feet.	*Feet.*	*Second-feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
13	June 2, 1916	4.4	37.2	221.0	131.3	1.68	2.60	0.000267	63.9	0.0272	*Course*, straight; 948 feet long. *Cross section*, slight variations in shape, abrupt variations in size. *Side slopes*, quite irregular, particularly upper part. *Bottom*, fairly regular. *Soil*, dark silty loam. *Condition*, considerable growth in upper portion of channel, none in lower; silty material deposited on bed and sides of channel. *Constructed*, 1910. (See Pl. XIV, fig. 2; and fig. 7 E.)
14	May 22, 1916	6.9	47.2	614.0	270.8	2.27	4.19	.000261	68.6	.0278	
	....	[1] 10.0	....	....	....	....	....	....	....	....	

MONONA-HARRISON DREDGED CHANNEL, NEAR ONAWA, IOWA, 1917.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	C.	n.	Description of channel.
15	June 8, 1917	8.5	59.8	499.0	308.0	1.62	4.82	0.000178	55.3	0.0362	Practically no change in channel since measurements were made in 1916.
16	June 9, 1917	8.8	61.5	546.5	322.1	1.70	4.92	.0001475	63.2	.0320	
	....	[1] 10.0	....	....	....	....	....	....	....	....	

LITTLE SIOUX RIVER CUT-OFF DREDGED CHANNEL, NEAR TURIN, IOWA, 1916.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	C.	n.	Description of channel.
17	June 2, 1916	11.3	90.6	2,907.0	839.7	3.47	8.62	0.000480	54.0	0.042	*Course*, straight; 1,212 feet long. *Cross section*, slight variations in shape, abrupt variations in size. *Side slopes*, left side quite regular; right side irregular. *Bottom*, uneven and rather irregular. *Soil*, upper, dark silty loam; lower, heavy firm clay. *Condition*, considerable vegetation on both slopes of channel; very little silt in channel. *Constructed*, 1910. (See Pl. XV, fig. 1; and fig. 7 F.)
18	May 22, 1916	12.7	92.0	3,208.0	969.4	3.31	9.61	.000398	53.5	.044	
19	May 24, 1916	14.2	94.7	3,380.0	1,107.0	3.05	10.62	.000305	53.6	.046	
	....	[1] 20.0	....	....	....	....	....	....	....	....	

LITTLE SIOUX RIVER CUT-OFF DREDGED CHANNEL, NEAR TURIN, IOWA, 1917.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	C.	n.	Description of channel.
20	June 9, 1917	18.8	113.2	4,505.5	1,332.8	3.38	10.77	0.000934	33.8	0.076	*Course*, straight; 1,654 feet long. *Cross section*, considerable variation in shape; very abrupt variations in size. *Side slopes*, left side, considerably rougher than during 1916; right side, extremely rough and irregular. *Bottom*, uneven and irregular. *Soil*, same as described next above. *Condition*, since 1916 measurements, right bank covered with trees and willows, which have slipped into channel; channel in very bad condition. *Constructed*, 1910. (See Pl. XV, fig. 2; and fig. 7 F.)
21	June 8, 1917	[1] 19.1	113.6	4,887.0	1,374.0	3.56	11.0	.000932	35.0	.075	

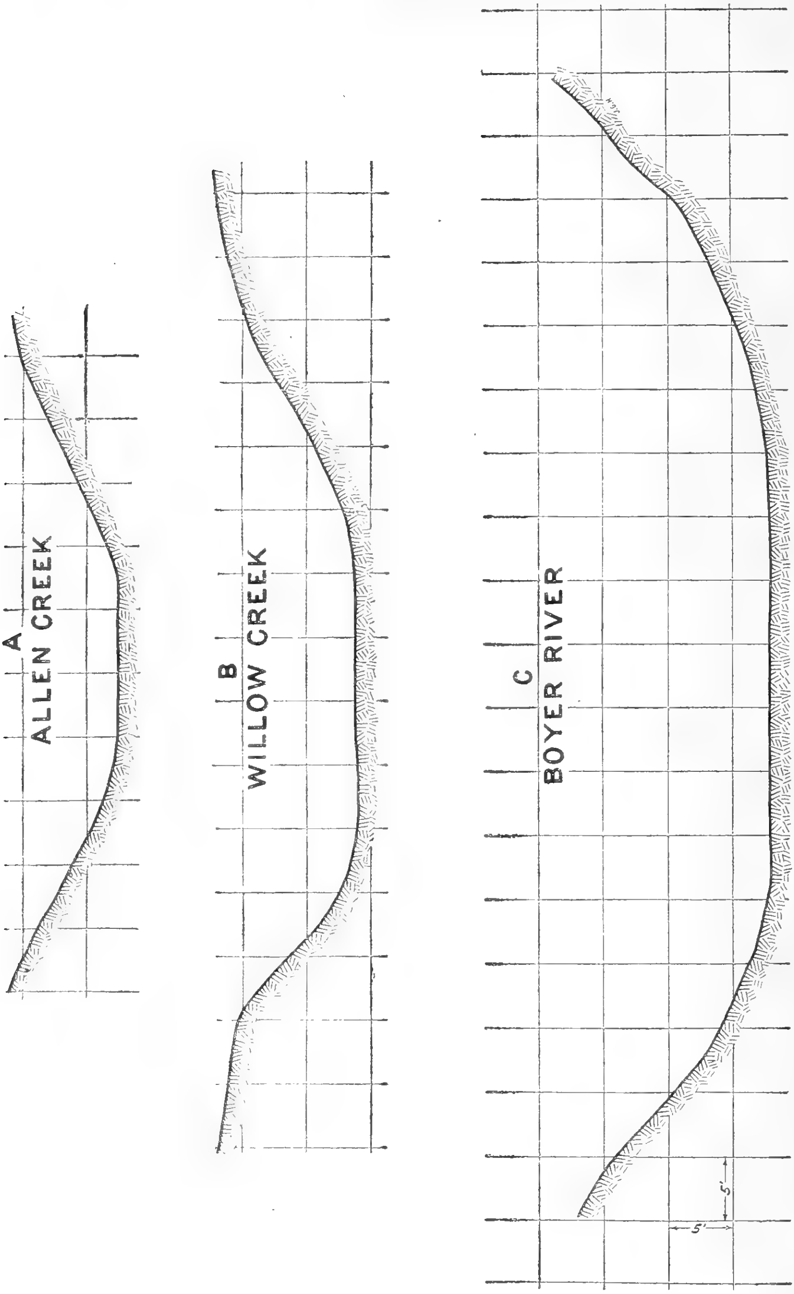
[1] Average maximum depth at bankful stage.

ALLEN CREEK.

Gaugings of Allen Creek were made from the first highway bridge north of the Chicago & North Western Railroad about 1 mile west of Missouri Valley. The upstream end of the course for slope measurements, which was 794 feet in length, was about 130 feet downstream from the bridge. A view of the slope course is shown in Plate XII, figure 2. It is seen from this view and from figure 7 *A*, that the course is straight and that the side slopes of the channel are very smooth and regular and stand at a slope of about 1½ to 1. No appreciable amount of vegetation can be seen in the channel. This stream was enlarged to its present size during the summer of 1916, and the measurements for values of n were made about one year later. The soil in the channel is a heavy dark loam. The bottom of the channel is generally covered with soft mud to a depth of one-half to 1 foot, and the side slopes, after high stages in the channel, are left covered with a coat of slippery, slimy mud or silt. This coat can be seen by an inspection of Plate XII, figure 2. Two values of n were determined for practically bankful stages. These values are 0.0140 and 0.0142 (Table 4, measurements 1 and 2), which are exceedingly low for dredged drainage ditches and may be ascribed in part to the excellent condition of the channel and the uniformity of cross section (fig. 8 *A*), but mostly to the actual lining of the entire perimeter of the channel with a coating of slimy, slippery mud. This coating of mud no doubt greatly decreased the friction between the moving water and perimeter of the channel.

WILLOW CREEK.

Discharge measurements of the Willow Creek dredged channel were made at the Chicago & North Western Railroad bridge near Missouri Valley. The slope posts for the upper end of the slope course were set about 155 feet below the bridge, the length of the course being 1,004 feet. It can be seen from figures 7 *B*, and 8 *B*, and Plate XIII, figure 1, that the slope course is straight and very uniform in cross section. The left side slope is much more regular and smooth than the right side slope and resembles the slopes of the Allen Creek ditch in this respect. Some vegetation can be seen in the channel, but it was not present when the gaugings and slope measurements were made. This channel is comparatively new, having been enlarged to its present size during the summer of 1916, and these measurements were made and views taken about one year later. The soil in the channel is a heavy dark loam, similar to that found in the Allen Creek channel. The bottom of the channel was covered with from 1 to 1½ feet of mud during these experiments, and the coating of the perimeter of the channel with slimy mud during high stages was practically the same as in Allen Creek. In general, the channel


A
ALLEN CREEK
B
WILLOW CREEK
C
BOYER RIVER
5'
5'

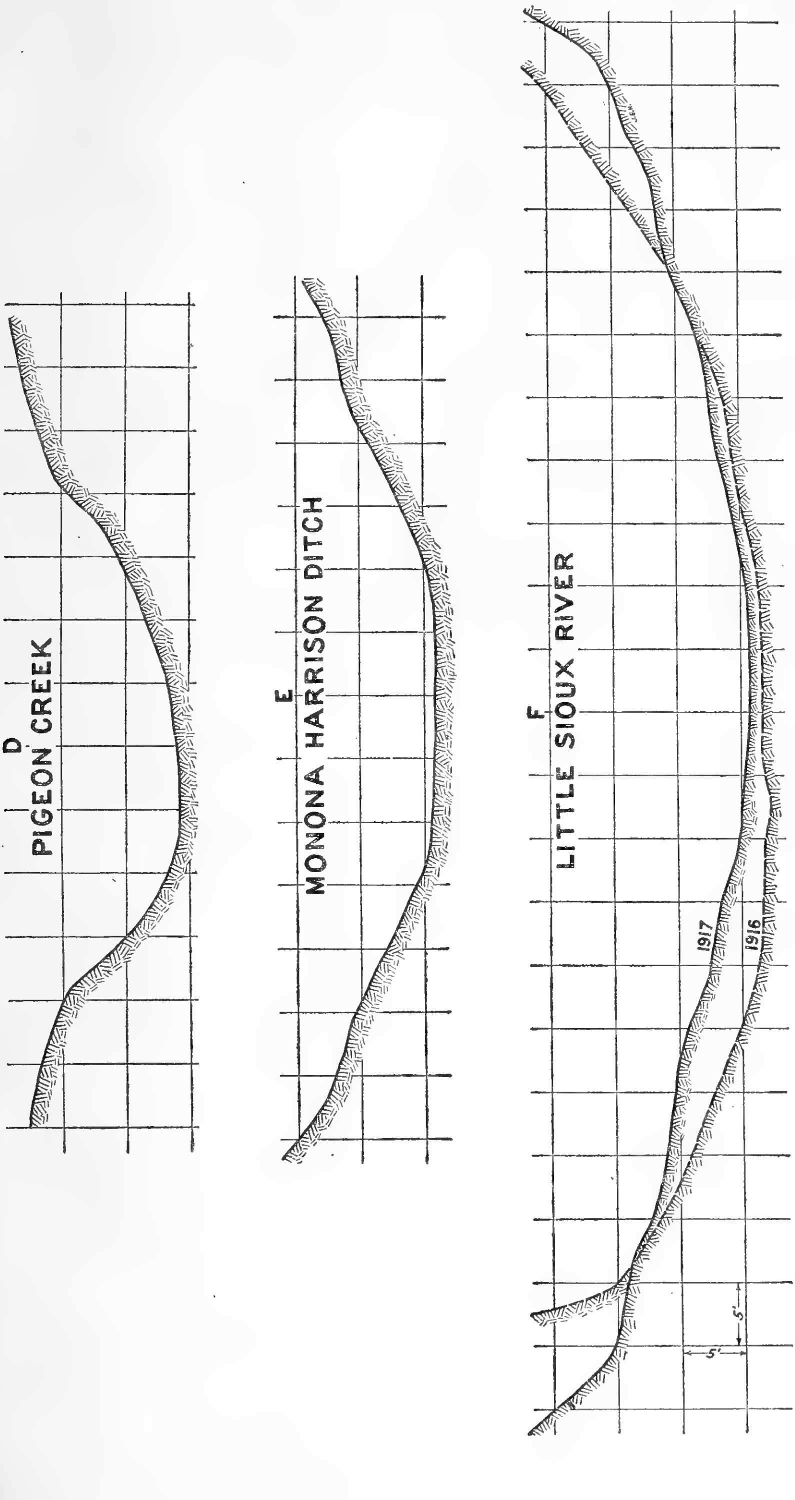


FIG. 7.—Average cross sections of channels for experiments in western Iowa.

is very similar to that of Allen Creek, and the values of n obtained, as given in Table 4, are practically the same as those obtained for Allen Creek.

BOYER RIVER.

Gaugings of the Boyer River were made at the Lincoln Highway bridge about 1 mile from Missouri Valley. The downstream end of the slope course was 197 feet above the bridge. The length of the slope course was 868 feet. A view of the slope course looking upstream is shown in Plate XIII, figure 2. The downstream slope posts are barely visible on the left-hand side of the view, just above

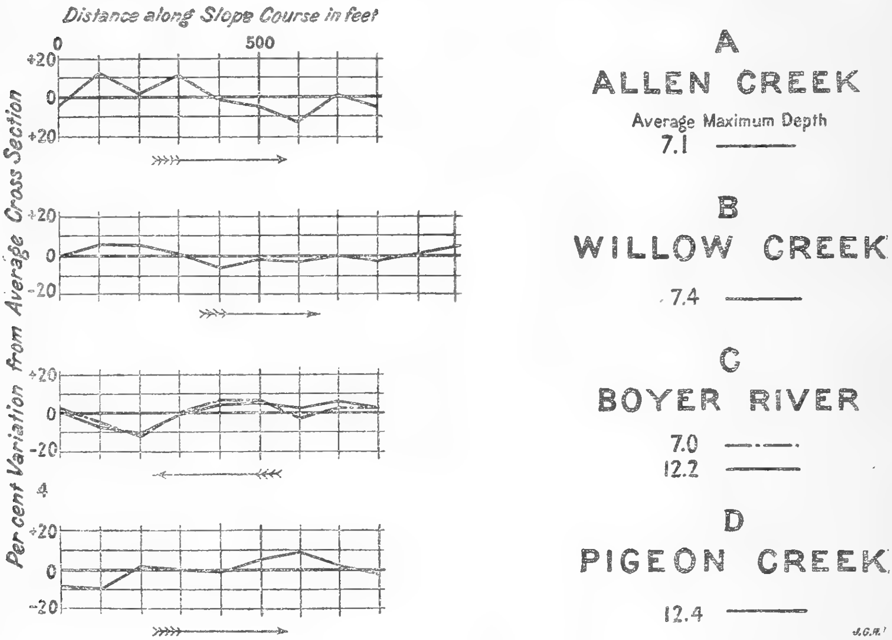


FIG. 8.—Graphs for experiments in western Iowa, showing per cent variation from average cross sectional area for all cross sections along slope course.

the break in the bank. It can be seen that above this break in the bank the course of the channel is straight and fairly uniform in cross section (fig. 8 *C*). The sides of the upper part of the channel stand at a slope of about 1 to 1 (see fig. 7 *C*). The soil in the upper part of the sides of the channel consists of a dark loam and in the lower part it is a hard yellow clay. The channel is practically free from any form of vegetation, which condition is largely due to its rapid enlargement caused by erosion. Since the channel was constructed, in 1910, it has enlarged to almost double its original size.

During flood stages the condition of the channel was very similar to that described for the Allen and Willow Creek channels. After the water subsided the sides of the channel were left coated with a thin layer of múd. The values of n obtained (Table 4) are higher than those obtained for Allen and Willow Creeks, which is attributed to the fact that the sides of the channel are considerably more irregular, as may be seen by comparing the views of the channels. Also, it is believed that the reduction of friction, due to the coating of mud on the sides of the channels, was much more effective on the rather flat side slopes of Willow and Allen Creeks than on the steeper side slopes of the Boyer River channel. It will be noted that, for the Boyer River channel, the value of n increases as the stage decreases. This is due, no doubt, to the fact that the lower part of the channel is more irregular than the upper part.

PIGEON CREEK.

Gaugings of Pigeon Creek were made at the highway bridge about one-half mile above the Chicago & North Western Railroad, near the town of Crescent. A view of the course of slope measurements is shown in Plate XIV, figure 1. This view was taken looking downstream from the gauging station. The upstream slope posts, which were about 65 feet below the bridge, can be seen on the right-hand side of the view.

The upper portion of the sides of the channel stand at a slope of about 1 to 1 (see figs. 7 *D*, and 8 *D*). There was very little vegetation in the channel when the gaugings and slope measurements were made. The soil in the channel is a heavy dark loam, and the bottom of the channel is generally covered with ½ to 1 foot of mud. The channel was dug in 1907, and has increased somewhat in depth since that time but not much in width. The right bank of the channel is rather smooth and regular, while the left bank is rough and irregular. During flood stages the channel was coated with mud, as described for the channels near Missouri Valley.

In Table 4, measurements 11 and 12, are shown two values of n obtained for high stages in the channel. These values are much larger than those obtained for Willow and Allen Creeks, which is perhaps due to the rougher condition and greater fall of the channel, both of which conditions probably rendered less effective the mud coating in reducing friction.

MONONA-HARRISON DITCH.

A view of the slope course on the Monona-Harrison ditch, near Onawa, is shown in Plate XIV, figure 2. This view was taken looking upstream from the gauging station, which was located at the highway bridge on the Turin-Onawa road. The length of the slope course was 948 feet. Experiments were made during the years 1916 and 1917, and not much difference was found in the size and condition of the channel for the two sets of measurements. In Table 4 are given the values of n obtained for the years 1916 and 1917, respectively. From this table it is seen that the values of n obtained for the low stages during 1916 are lower than those obtained for the higher stages during 1917. This is due to the fact that the upper portion of the channel is irregular and covered with growth, as may be seen from the view of of the channel. During the gaugings and slope measurements the water was not as fully laden with silt as in the case of the ditches in the vicinity of the Missouri Valley, nor were the sides of the channel so well coated with mud. The bed and the flatter portions of the sides of the channel were covered with silt, varying in depth from $\frac{1}{2}$ to $1\frac{1}{2}$ feet. (See fig. 7 *E* for average cross section of channel.)

LITTLE SIOUX RIVER CUT-OFF.

Gaugings of the Little Sioux River were made from the highway bridge on the Onawa-Turin road, about one-half mile from Turin. Values of n for the channel were obtained during 1916 and 1917. Views of the slope course taken during June, 1916, and June, 1917, are shown in Plates XV, figures 1 and 2. The length of the slope course for the measurements made in 1916 was 1, 212 feet, and for those made in 1917 was 1,654 feet. The slope course was located on the straight stretch of channel above the gauging station at the highway bridge. The soil in the upper part of the channel is a dark silty loam, while in the lower part it is a heavy firm clay. There was practically no silt in the bed of the channel during the time that the experiments were made. The channel during 1916 was fairly uniform in section, and the left bank, which is shown on the right-hand side of the view (Pl. XV, fig. 1), was quite regular. The right bank was somewhat irregular, due to caving. (See fig. 7 *F*, for average cross sections of the channel.) There was some vegetation on both side slopes of the channel, as may be seen from the view. The values of n obtained for this channel, shown in Table 4, are about what would be expected for a channel in its condition.

Plate XV, figure 2, shows the condition of the same channel in June, 1917. The right bank, which in 1916 was covered with trees, has caved into the channel, and the left bank is considerably rougher than it was in June, 1916. The two values of n obtained, 0.075 and 0.076, are considerably higher than those obtained in 1916. This may readily be ascribed to the caving of the right bank, which carried into the channel large trees and other obstructions. The water during the experiments was not laden with silt, as in the case of the ditches near Missouri Valley, and the channel was not coated with mud after the subsidence of the water.

DISCUSSION OF WESTERN IOWA EXPERIMENTS.

The low values of n obtained for the Allen and Willow Creek Ditches (0.0128 to 0.0143) are, so far as the writer knows, without precedent for dredged channels. From a close examination of the views of these channels one would expect low values of n for channels with such regular and smooth side slopes and uniform cross sections. However, the fact that the values of n are so low can not be attributed alone to these conditions, since a low value of n was obtained for a bankful stage of the Boyer River channel, which does not fulfill these ideal conditions of regularity and uniformity. The low values are therefore due mostly, no doubt, to the coating of slick, silty mud with which the perimeters of the channel were covered, the tendency being to smooth up irregularities. It is not conclusively apparent why the values of n for Pigeon Creek are so much higher than for Willow Creek since the conditions of the ditches are somewhat similar. It is possible that the slight difference in the condition of the channel and the greater fall rendered the mud coating less effective in reducing frictional resistance.

In view of the results obtained for Pigeon Creek, the Monona-Harrison Ditch, and the lower part of the Boyer River channel, it is possible that the effectiveness of this coating of mud in reducing friction is affected by vegetation, roughness of channel, angle of side slopes, irregularity of cross section, and slope of channel. It is not recommended that such low values of n as obtained for Allen and Willow Creeks be employed in the design of proposed dredged drainage channels unless there is no question but that all the conditions of the Allen and Willow Creek channels will be duplicated. It should also be remembered that these ditches are comparatively new, and unless the proposed ditches are to be carefully maintained to keep the channels free of growth and obstructions, and unless there is good reason to believe that they will retain their original smooth slopes and uniform cross section, a low value of n should not be used, even though the silty conditions as described above could be expected to prevail.

EXPERIMENTS IN NORTH CAROLINA.

Values of n were determined for five courses of channels in Back Swamp and Jacob Swamp, North Carolina, namely: Turkey Branch, Back Swamp, Jacob Swamp at Lovett Road, Little Jacob Swamp, and Jacob Swamp at the Nashville & Chattanooga Railroad. These experiments were made by A. D. Morehouse, formerly a drainage engineer of this bureau.

TABLE 5.—*Results of experiments made in North Carolina.*

TURKEY BRANCH HAND-DUG CHANNEL NEAR PEMBROKE, N. C.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
		Feet.	*Feet.*	*Sec. feet.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
1	Jan. 29, 1915	0.7	4.8	2.5	3.2	0.78	0.56	0.000915	34.5	0.0325	*Course*, straight; 200 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 10 A. *Side slopes*, quite regular. *Bottom*, fairly regular; changes occur due to silting and erosion. *Soil*, sandy clay. *Condition*, free from vegetation of all kinds. *Constructed*, summer 1913. (See Pl. XVI, fig. 1; and fig. 9 A.)
2	Jan. 14, 1915	.9	5.5	4.3	3.9	1.11	.62	.000790	50.2	.0243	
3	Jan. 20, 1915	.95	5.7	4.7	4.0	1.17	.64	.001010	46.0	.0266	
	....	[1]5.0	....	....	....	....	....	....	....	....	

BACK SWAMP DREDGED CHANNEL NEAR LUMBERTON, N. C.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
4	Apr. 22, 1915	2.5	22.5	28.5	25.3	1.13	1.22	0.000792	36.3	0.0382	*Course*, straight; 250 feet long. *Cross section*, abrupt variations in shape; for variation in size, see fig. 10 B. *Side slopes*, fairly regular. *Bottom*, fairly regular, some holes. *Soil*, sandy clay. *Condition*, mat of overhanging ragged roots on both side slopes; no weeds or grass in channel; some roots in bottom. *Constructed*, winter 1913. (See Pl. XVI, fig. 2; and fig. 9 B.)
5	Feb. 10, 1915	2.9	23.1	40.0	32.0	1.25	1.45	.000880	35.0	.0417	
6	May 17, 1915	3.1	23.3	58.6	35.6	1.65	1.57	.000880	44.4	.0340	
7	Feb. 3, 1915	4.4	24.6	129.6	66.0	1.96	2.51	.000624	49.5	.0345	
8	Jan. 20, 1915	5.1	25.2	171.9	83.1	2.07	2.98	.000600	49.0	.0363	
9	May 13, 1915	5.7	25.8	232.5	98.8	2.35	3.34	.000730	47.7	.0383	
10	Jan. 25, 1915	5.75	26.0	235.1	99.3	2.37	3.34	.000640	51.2	.0359	
	....	[1]6.5	....	....	....	....	....	....	....	....	

JACOB SWAMP DREDGED CHANNEL AT LOVETT ROAD, NEAR LUMBERTON, N. C.

No.	Date of observation.	Average maximum depth.	Average surface width.	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
11	Feb. 22, 1915	1.5	22.3	6.5	13.0	0.50	0.67	0.000493	27.6	0.0405	*Course*, straight; 300 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 10 C. *Side slopes*, fairly regular. *Bottom*, fairly even and regular. *Soil*, sandy clay loam. *Condition*, not much vegetation in channel, except for last measurement, at which time two-thirds of the bottom and side slopes were covered with water grass. *Constructed*, April, 1913. (See Pl. XVII, fig. 1; and fig. 9 C.)
12	Jan. 19, 1915	2.2	21.4	30.1	28.3	1.06	1.19	.000317	54.6	.0262	
13	Jan. 25, 1915	2.3	24.7	32.0	29.8	1.07	1.23	.000443	45.7	.0312	
14	Feb. 2, 1915	2.5	25.2	43.7	35.0	1.25	1.41	.000373	54.6	.0274	
15	May 13, 1915	3.2	26.0	51.0	49.4	1.03	1.81	.000550	32.6	.0475	
	....	[1]6.0	....	....	....	....	....	....	....	....	

LITTLE JACOB SWAMP DREDGED CHANNEL NEAR LUMBERTON, N. C.

DURING WINTER MONTHS.

16	Feb. 22, 1915	0.9	13.0	6.5	10.3	0.63	0.69	0.000448	35.8	0.0332	*Course*, straight; 500 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 10 D. *Side slopes*, fairly regular. *Bottom*, quite even and regular. *Soil*, clay; sandy bottom due to silting. *Condition*, some moss along course; very little foreign material in channel. *Constructed*, July, 1913. (See Pl. XVII, fig. 2; and fig. 9 D.)
17	Jan. 13, 1915	1.0	13.6	13.7	12.4	1.10	.79	.000738	45.4	.0282	
18	Jan. 19, 1915	1.5	17.2	24.1	19.6	1.23	1.08	.000630	47.1	.0293	
19	Jan. 25, 1915	1.6	17.5	26.7	20.5	1.30	1.11	.000566	52.0	.0270	
	....	[1] 7.0	....	....	....	....	....	....	....	....	

DURING SUMMER MONTHS.

20	June 28, 1915	0.65	10.0	2.2	6.3	0.35	0.50	0.000308	28.2	0.0362	*Course*, same as next above. *Condition*, light growth of grass and weeds along edge of low water flow.
21	June 15, 1915	.7	10.5	2.8	6.8	.41	.53	.000314	31.7	.0335	
22	June 11, 1915	.8	11.0	4.5	8.6	.52	.62	.000322	36.8	.0310	
23	May 19, 1915	.9	12.0	5.4	10.1	.53	.70	.000360	33.3	.0348	
24	May 15, 1915	1.4	17.0	15.4	17.4	.89	1.01	.000318	49.7	.0272	
25	May 13, 1915	2.2	20.0	29.5	32.9	.90	1.55	.000176	54.5	.0275	
	....	[1] 7.0	....	....	....	....	....	....	....	....	

JACOB SWAMP DREDGED CHANNEL AT N. & C. R. R. NEAR LUMBERTON, N. C.

DURING WINTER MONTHS.

26	Mar. 4, 1915	1.1	19.5	9.6	14.9	0.64	0.67	0.000593	32.1	0.0357	*Course*, straight; 300 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 10 E. *Side slopes*, irregular. *Bottom*, fairly even and regular. *Soil*, clay loam. *Condition*, some roots and dead vegetation in channel. *Constructed*, April, 1913. (See Pl. XVIII, fig. 1; and fig. 9 E.)
27	Feb. 22, 1915	1.3	20.8	17.7	19.2	.92	.84	.000470	46.2	.0276	
28	Jan. 19, 1915	2.3	25.1	64.3	47.7	1.35	1.72	.000503	45.9	.0357	
29	Jan. 25, 1915	2.4	25.9	71.1	49.7	1.43	1.78	.000350	57.2	.0276	
30	Feb. 2, 1915	2.9	26.3	112.8	65.2	1.73	2.21	.000531	50.5	.0330	
	....	[1] 6.5	....	....	....	....	....	....	....	....	

DURING SUMMER MONTHS.

31	June 11, 1915	1.2	19.0	8.9	22.4	0.40	0.93	0.000560	17.6	0.0680	*Course*, same as next above. *Condition*, growth of water grass and weeds in channel.
32	May 19, 1915	1.4	20.2	11.8	25.6	.46	1.05	.000590	18.4	.0675	
33	May 17, 1915	1.6	21.0	20.6	31.2	.66	1.25	.000483	26.8	.0508	
34	May 15, 1915	2.1	23.2	37.8	43.8	.86	1.64	.000437	32.0	.0470	
35	May 13, 1915	3.4	27.7	96.2	79.4	1.21	2.56	.000423	36.7	.0470	
	....	[1] 6.5	....	....	....	....	....	....	....	....	

[1] Average maximum depth at bankful stage.

TURKEY BRANCH.

A straight course 200 feet long was selected for slope measurements on the Turkey Branch channel just above the Atlantic Coast Line Railroad southwest of Pembroke. This channel is small and was hand-dug (Plate XVI fig. 1; and fig. 9 *A*). At the time of the experiments the channel was very uniform in cross section for a bankful stage; it had regular side slopes and was free from growth of any kind. The values of *n* obtained were only for very low stages. As may be seen from Table 5, the average maximum depth for the channel at bankful stage was 5.0 feet, and only 0.95 foot for the highest stage for which *n* was determined. The cross sectional area of the lower part of the channel varied considerably in size (fig. 10 *A*).

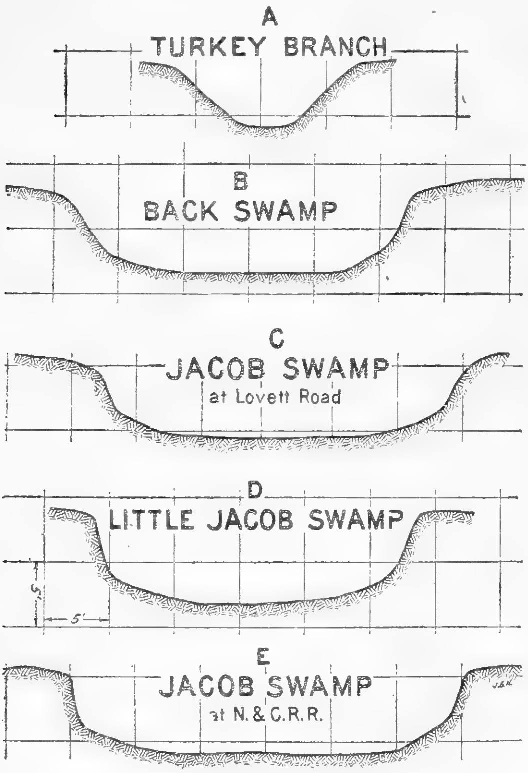


FIG. 9.—Average cross sections of channels for experiments in North Carolina.

BACK SWAMP.

A straight course of channel 250 feet in length was used for slope measurements on the Back Swamp channel. It was located just west of the Sunday Ford Road and about 8 miles west of Lumberton. At the time of these measurements the channel was quite uniform in cross section, and the side slopes were quite regular (fig. 10, *B*). The side slopes have been eroded considerably so as to be nearly vertical, leaving a mat of overhanging ragged roots on either bank. Owing to a comparatively swift current, there were no weeds, grass, or other vegetation on the bottom or side slopes, but there were a number of large tree roots in the channel. Plate XVI, figure 2; and figure 9 *B*, show the condition and average cross section of channel, and Table 5 shows the values obtained for *n*. Of the five channels for which experiments were made, this is the only one where a value of *n* was determined for a near bankful stage.

B. P. R.—D3063

FIG. 1.—SLOPE COURSE OF JACOB SWAMP DREDGED CHANNEL AT LOVETT ROAD, NEAR LUMBERTON, N. C. (SEE TABLE NO. 5.)

B. P. R.—D3065

FIG. 2.—SLOPE COURSE OF LITTLE JACOB SWAMP DREDGED CHANNEL, NEAR LUMBERTON, N. C., 1915. (SEE TABLE NO. 5.)

B. P. R.—D3064

FIG. 1.—SLOPE COURSE OF JACOB SWAMP DREDGED CHANNEL AT N. & C. R. R., NEAR LUMBERTON, N. C., 1915. (SEE TABLE NO. 5.)

B. P. R.—D941

FIG. 2.—COURSE OF MAIN DREDGED CHANNEL, NEAR FELLSMERE, FLA., ADJOINING SLOPE COURSE. THIS VIEW REPRESENTS FAIRLY WELL THE CONDITION OF THE CHANNEL ALONG THE SLOPE COURSE. 1917. (SEE TABLE NO. 6.)

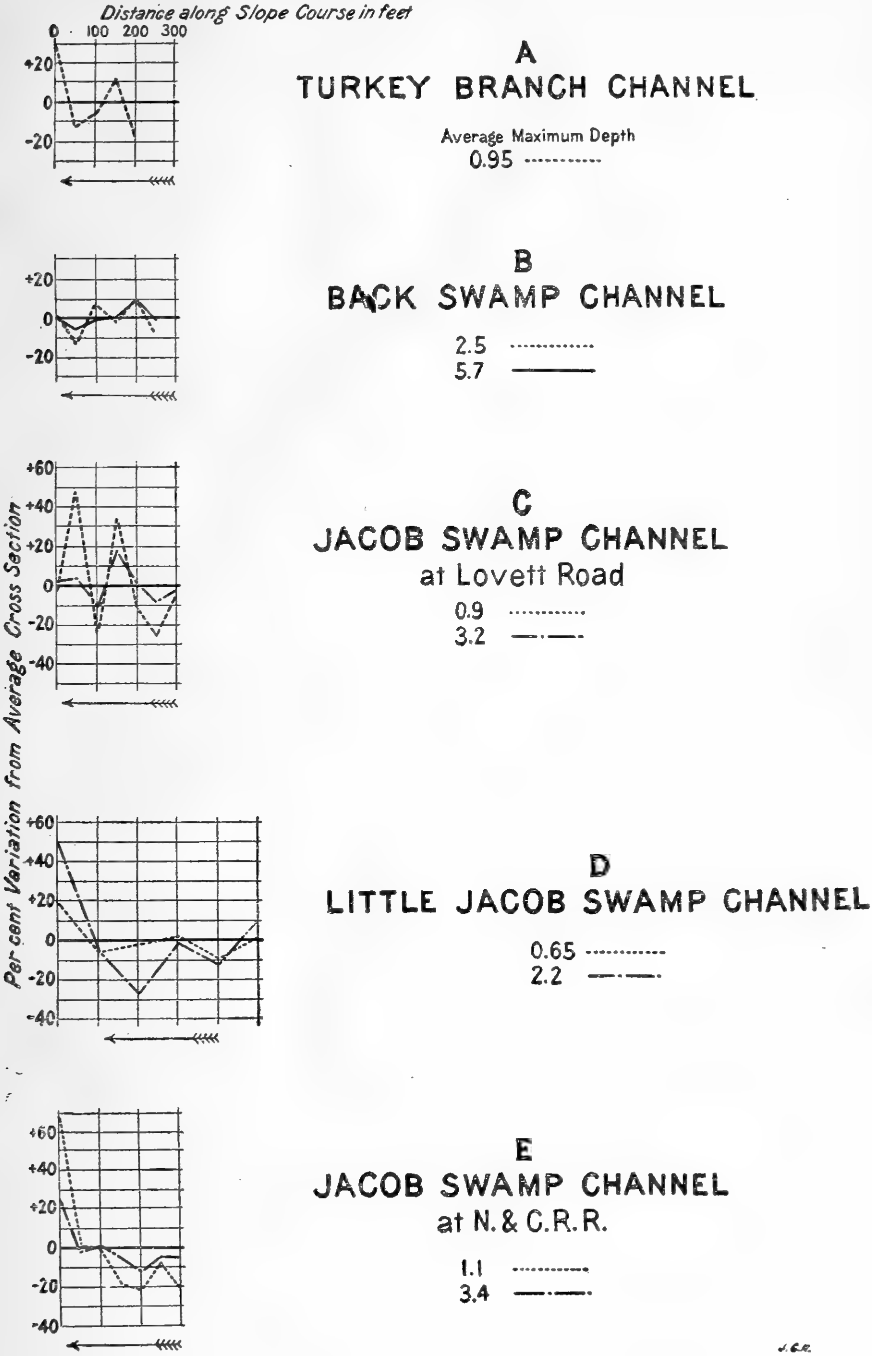


FIG. 10.—Graphs for experiments in North Carolina, showing per cent variation from average cross-sectional area for all cross sections along slope courses.

JACOB SWAMP AT LOVETT ROAD.

A slope course 300 feet in length, just west of the Lovett Road and about 2 miles south of Lumberton, was selected for slope measurements on this channel. The cross section was fairly uniform for the higher stages and the side slopes and bottom fairly regular. For the lower stages there was considerable variation in cross section (fig. 10 *C*). There was practically no vegetation in the channel when the measurements were made during January and February, but for the single measurement made during May about two-thirds of the bottom and side slopes were covered with water grass. (See Plate XVII, fig. 1, for view and fig. 9 *C*, for average cross section of the channel.)

During low water the thread of the stream wanders from side to side, which, with the large and abrupt variations in cross sections, is no doubt responsible for the high value of n obtained for the lowest stage (measurement 11, Table 5). The high value obtained for measurement 15 is due, of course, to the growth of grass in the channel. This value was obtained for about half-bankful stage. Values for higher stages were not obtained, so that none of the values of n given in Table 5 apply to the channel when flowing full.

LITTLE JACOB SWAMP.

A straight course 500 feet in length, just west of the Lovett Road about 2½ miles south of Lumberton, was used for slope measurements. This course was fairly uniform in cross section for a distance of about 450 feet from the upper end of the slope course, with quite regular side slopes and bottom (fig. 10 *D*). There was very little growth in the channel during the winter months. Plate XVII, figure 2, is a view of the channel and figure 9 *D*, shows the average cross section. During the summer months grass and weeds appear in the channel, especially along the edge of the water, and there were several patches of moss along the slope course. There was not sufficient growth in the channel to produce a very marked effect upon the value of n, as may be seen from the small difference in the results of the measurements as given in Table 5 for the winter and summer months. The values of n were obtained for only very low stages.

JACOB SWAMP AT NASHVILLE & CHATTANOOGA RAILROAD.

The slope course used on this channel was 300 feet in length and was located just west of the Nashville & Chattanooga Railroad trestle, about 2 miles south of Lumberton. The cross section of this course of channel was fairly uniform for a distance of about 275 feet from the upper end of the course, but the side slopes were rather irregular (fig.

10 *E*) There were some roots and dead vegetation in the channel during the winter months. Silting had occurred along the course, and there was a mud island 3 feet wide by 10 feet long lying lengthwise of the channel a short distance above the lower end of the slope course. During the summer months the island was covered with water grass. There was also a growth of grass along the edge of low-water stages and two patches of grass in the channel along the course.

The highest stages for which values of n were determined were about half-bankful. Referring to Table 5, it can be seen that the values of n obtained during the summer months are higher than those obtained during the winter months, owing to the growth of grass in the channel; also that the values for the summer months increase as the stage decreases, due no doubt to the fact that for the lower stages the grass filled a much greater proportion of the cross-sectional area of the channel. Plate XVIII, figure 1, is a view of the channel, and figure 9 *E* shows the average cross section.

DISCUSSION OF NORTH CAROLINA EXPERIMENTS.

Attention is especially called to the fact that in these experiments values of n were not obtained for bankful stages, and this should be kept in mind when comparing the views and descriptions of the channels with the values of n obtained. A value of n for a near-bankful stage was obtained on the Back Swamp channel, but in the other channels the highest stages for which values of n were determined were about half, and in some instances considerably less than half, of a bankful stage.

The chief value of these experiments lies in the fact that values of n were determined before and after the growth of grass in three of the channels, from which a general idea can be obtained as to the retarding effect of grass upon the flow in water courses.

With the exception of Back Swamp the discharges of the channels were quite small, and for this reason it is not believed that the results are as accurate as were obtained for the other experiments herein discussed, since the effect of errors in making small discharge measurements is usually greater than in the measurement of large discharges.

EXPERIMENTS IN FLORIDA.

These experiments were made on the main channels of the Fellsmere, Vero, and Fort Pierce Drainage Districts, and on two courses of Lateral No. 2 of the Fort Pierce Drainage District. They were conducted by F. E. Staebner, drainage engineer of this bureau, during 1916 and 1917.

TABLE 6.—*Results of experiments made in Florida.*

No.	Date of observation.	Average maximum depth.	Average surface width	Discharge.	Average cross section.	Mean velocity.	Mean hydraulic radius.	Slope of water surface.	Coefficient in formula $V=C\sqrt{RS}$ C.	Coefficient of roughness n.	Description of channel.
	MAIN DREDGED CHANNEL NEAR FELLSMERE, FLA., 1916.										
		Feet.	*Feet.*	*Sec.-ft.*	*Sq. ft.*	*Ft. per sec.*	*Feet.*				
1	Oct. 12, 1916	1.40	45.5	48.8	48.2	1.01	1.05	0.000328	54.5	0.0253	*Course*, straight; 2,000 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 12 A. *Side slopes*, lower, fairly regular; upper, rather irregular. *Bottom*, regular and even. *Soil*, coarse sand on bottom, clay on sides. *Condition*, some vegetation, principally dog fennel, for higher stages; practically no vegetation for lower stages. *Constructed*, November, 1911. (See Pl. XVIII, fig. 2).
2	Dec. 5, 1916	1.7	46.4	64.7	63.1	1.02	1.32	.000260	55.1	.0264	
3	Sept. 22, 1916	5.6	75.6	506.2	298.0	1.70	3.83	.000222	58.3	.0323	
4	....do........	5.7	76.5	534.0	302.2	1.77	3.83	.000198	64.2	.0292	
5	....do........	5.75	76.5	558.6	314.8	1.77	3.97	.000205	62.3	.0304	
	....	[1] 15.9	....	....	....	....	....	....	....	....	
	MAIN DREDGED CHANNEL NEAR FELLSMERE, FLA., 1917.										
6	Feb. 10, 1917	1.6	45.6	44.2	48.1	0.92	1.05	0.000259	55.8	0.0251	Condition of channel practically the same as during the 1916 measurements. For variation in size of channel see fig. 12 B. See fig. 11 A for cross section.
7	July 12, 1917	2.3	49.3	94.7	83.1	1.14	1.66	.000235	57.8	.0266	
8	Oct. 18, 1917	3.2	53.5	186.4	127.7	1.46	2.33	.000236	62.1	.0269	
9	Sept. 29, 1917	5.0	68.8	403.1	241.4	1.67	3.15	.000200	66.5	.0269	
10	....do........	7.6	88.5	746.8	441.9	1.69	4.86	.000185	56.3	.0355	
	....	[1] 15.9	....	....	....	....	....	....	....	....	
	MAIN DREDGED CHANNEL NEAR VERO, FLA., 1916.										
11	Aug. 14, 1916	1.2	47.7	41.1	44.6	0.92	0.92	0.000625	38.3	0.0337	*Course*, straight; 1,000 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 12 C. *Side slopes*, fairly uniform and regular for lowest three stages; quite rough and irregular for highest two. *Bottom*, fairly even and regular. *Soil*, sand on bottom, clay on sides. *Condition*, some vegetation in lower part of channel; flat sand bars. *Constructed*, December, 1912. (See Pl. XIX, fig. 1; and fig. 11 B.)
12	Nov. 21, 1916	2.2	52.8	131.2	91.4	1.44	1.70	.000178	50.4	.0319	
13	Oct. 5, 1916	2.8	55.9	201.4	128.6	1.57	2.25	.000305	60.0	.0278	
14	Oct. 28, 1916	5.3	67.2	569.5	285.7	1.99	4.11	.000479	44.9	.0432	
15	Oct. 29, 1916	6.9	73.1	955.2	397.3	2.40	5.26	.000538	45.1	.0460	
	....	[1] 10.0	....	....	....	....	....	....	....	....	
	MAIN DREDGED CHANNEL NEAR VERO, FLA., 1917.										
16	Sept. 12, 1917	3.2	57.9	290.2	136.9	2.12	2.33	0.000406	69.0	0.0244	Condition of channel, about the same as for the 1916 measurements. For variation in size of channel see fig. 12 D.
17	Oct. 19, 1917	4.7	67.6	533.2	234.9	2.27	3.41	.000407	61.1	.0299	
18	Sept. 27, 1917	5.1	68.9	577.2	260.0	2.22	3.68	.000416	56.8	.0327	
19	Sept. 25, 1917	5.7	71.3	712.5	307.1	2.32	4.18	.000571	47.6	.0404	
	....	[1] 10.0	....	....	....	....	....	....	....	....	

MAIN DREDGED CHANNEL NEAR FORT PIERCE, FLA., 1916.

20	Dec. 8, 1916	1.7	23.0	6.9	29.9	0.23	1.26	0.000125	18.3	0.0700	*Course*, straight; 1,032 feet long. *Cross section*, not much variation in shape; for variation in size, see fig. 12 E. *Side slopes*, rather irregular. *Bottom*, rather rough. *Soil*, hard clay. *Condition*, some water weeds on bottom; growth of grass and lilies near water edge at low stage. (See Pl. XIX, fig. 2; and fig. 11 C.)
21	Nov. 7, 1916	3.5	28.3	62.8	74.2	.85	2.62	.000178	39.3	.0435	
22	Nov. 18, 1916	3.7	30.6	77.5	79.5	.98	2.62	.000161	47.6	.0360	
23	Nov. 4, 1916	5.1	32.2	139.3	125.8	1.11	3.56	.000199	41.7	.0450	
24	Oct. 28, 1916	5.4	32.9	149.6	135.0	1.11	3.77	.000203	40.1	.0475	
	....	[1] 9.0	....	....	....	....	....	....	....	....	

MAIN DREDGED CHANNEL NEAR FORT PIERCE, FLA., 1917.

25	Sept. 13, 1917	2.9	20.3	13.4	37.3	0.36	1.73	0.000070	32.7	0.0450	*Course*, straight; 900 feet long. *Cross section*, not much variation in shape; for variation in size, see fig. 12 F. *Side slopes*, fairly regular. *Bottom*, irregular. *Soil*, hard clay. *Condition*, very little vegetation; channel was cleaned out and deepened since the 1916 measurements were made. (See fig. 11 C.)
26	Oct. 22, 1917	5.0	25.6	106.4	87.2	1.22	3.06	.000163	54.5	.0327	
27	Oct. 20, 1917	5.8	26.8	155.8	109.7	1.42	3.58	.000180	56.0	.0331	
28	Sept. 25, 1917	6.7	28.5	220.2	134.3	1.64	4.02	.000220	55.1	.0346	
29	Oct. 17, 1917	6.9	28.1	234.1	138.5	1.69	4.09	.000212	57.3	.0334	
	....	[1] 11.5	....	....	....	....	....	....	....	....	

LATERAL DREDGED CHANNEL NO. 2, COURSE A, NEAR FORT PIERCE, FLA.

30	Oct. 20, 1917	3.9	19.5	12.5	52.3	0.24	2.38	0.000027	29.9	0.0540	*Course*, straight; 503 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 12 G. *Side slopes*, rather irregular. *Bottom*, slightly irregular. *Soil*, hard clay. *Condition*, some vegetation in channel. (See Pl. XX, fig. 1; and fig. 11 D.)
31	Oct. 17, 1917	5.0	22.0	37.6	75.1	.50	2.87	.000064	36.9	.0470	
	....	[1] 8.5	....	....	....	....	....	....	....	....	

LATERAL DREDGED CHANNEL NO. 2, COURSE B, NEAR FORT PIERCE, FLA.

32	Oct. 20, 1917	2.2	30.1	10.5	38.8	0.27	1.27	0.000721	8.9	0.140	*Course*, straight; 500 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 12 H. *Side slopes*, rather irregular. *Bottom*, fairly regular; occasional low pockets that hold water during periods of no flow. *Soil*, sandy and easily eroded. *Condition*, bad; channel practically covered with vegetation. (See Pl. XX, fig. 2; and fig. 11 E.)
33	Oct. 17, 1917	3.3	39.4	31.4	76.7	.41	1.96	.000423	14.2	.108	
	....	[1] 4.0	....	....	....	....	....	....	....	....	

[1] Average maximum depth at bankful stage.

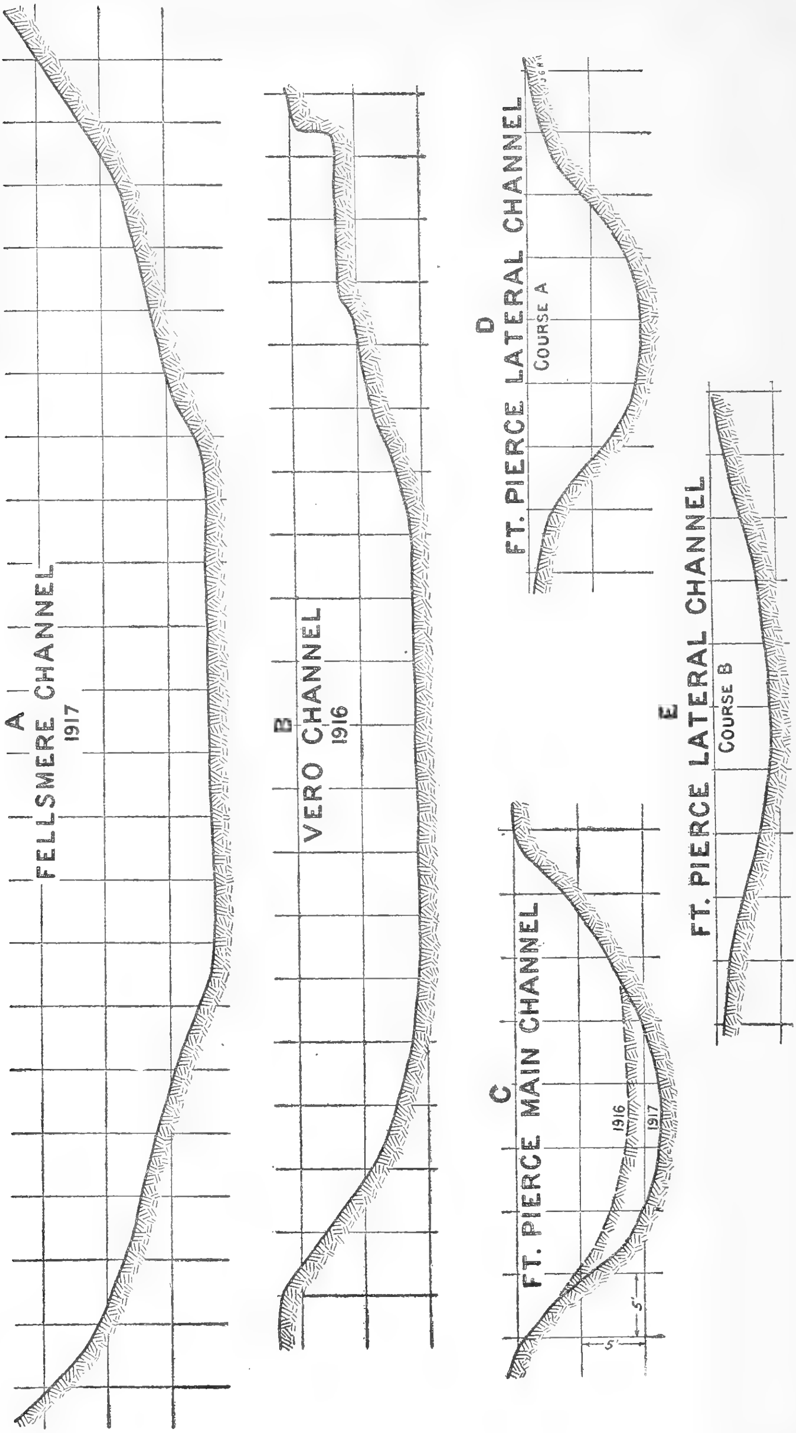


FIG. 11.—Average cross sections of channels for experiments in Florida.

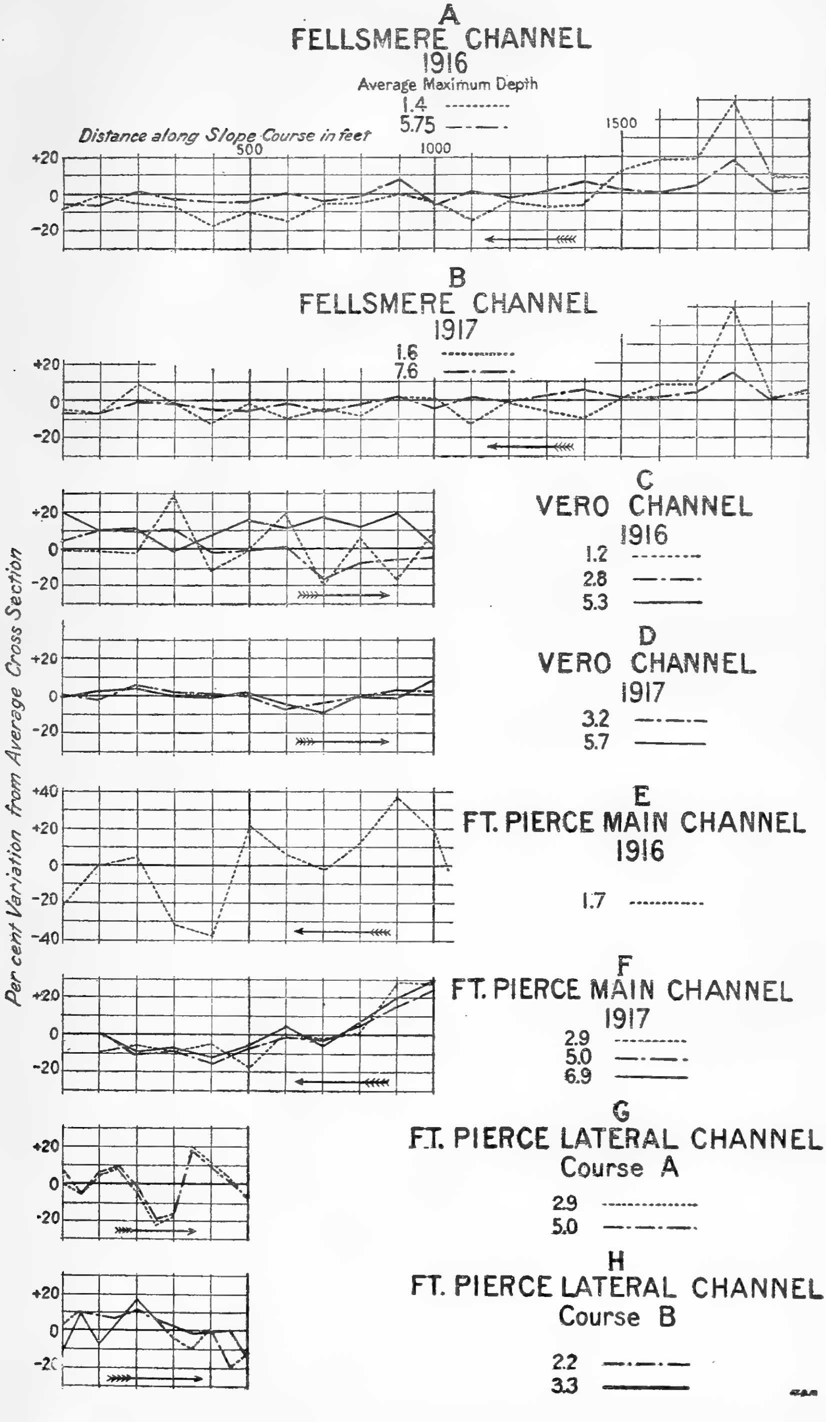


FIG. 12.—Graphs for experiments in Florida, showing per cent variation from average cross-sectional area for all cross sections along slope course.

MAIN CHANNEL NEAR FELLSMERE.

The slope course on this channel was straight and was 2,000 feet long. The gauging station was located about 100 feet below the downstream end of the slope course, which was about 3 miles north of Fellsmere. The gaugings were made from a footbridge about 10 feet upstream from the county highway bridge and supported by suspension brackets from the piling of that bridge. The channel was quite uniform in cross section, there being only one rather abrupt variation, which occurred near the upper end of the course (figs. 12 *A*, and 12 *B*). The bottom of the channel was broad and regular and quite evenly covered with sand. The side slopes were fairly regular and practically free from vegetation in the lower part of the channel, but rather irregular and covered with vegetation in the upper part (fig. 11 *A*, and Plate XVIII, fig. 2). With the exception of measurement 10, Table 6, for which the highest value of n was obtained, the measurements were made for stages almost wholly in the lower and better part of the channel. For the same part of the channel the values of n obtained during 1917 were somewhat lower than those obtained during 1916. This might be attributed to the fact that the cross section had become somewhat more uniform between the dates of the two sets of measurements, as appears from the graphs shown in figures 12 *A* and 12 *B*.

MAIN CHANNEL NEAR VERO.

Gaugings of this channel were made from a suspension footbridge near Vero. The upper end of the slope course, which was 1,000 feet long, was located about 40 feet downstream from the gauging station. The bottom was sandy, and there were several flat, broad sand bars in the channel during low water (Plate XIX, fig. 1; and fig. 11 *B*). There was some vegetation in the channel, which can be seen in the view just referred to. The cross-sectional area of the channel was quite uniform except for the lowest measurements, Nos. 11 and 12 (see Table No. 6 and figs. 12 *C* and 12 *D*). The side slopes for the three low-stage measurements made during 1916 were fairly regular, but for the three higher stage measurements, Nos. 14, 15, and 19, made at about half-bankful stages, the slopes were quite rough and irregular, owing to the fact that large lumps of the bank had sloughed off. The values of n obtained indicate that the retardation to flow was much greater in the upper part than in the lower part of the channel, which was apparently due to the caving of the banks in the upper part of the channel.

MAIN CHANNEL NEAR FORT PIERCE.

Gaugings of this channel were made from a suspension footbridge located about 3 miles west of Fort Pierce. The upper end of the slope course, which was 1,032 feet long, was located about 25 feet

B. P. R.—D798

FIG. 1.—SLOPE COURSE OF MAIN DREDGED CHANNEL, NEAR VERO, FLA., 1917. (SEE TABLE NO. 6.)

B. P. R.—D795

FIG. 2.—SLOPE COURSE OF MAIN DREDGED CHANNEL, NEAR FORT PIERCE, FLA., 1917. (SEE TABLE NO. 6.)

B. P. R.—D1353

FIG. 1.—SLOPE COURSE OF LATERAL DREDGED CHANNEL, NO. 2, COURSE A, NEAR FORT PIERCE, FLA., 1917. (SEE TABLE NO. 6.)

B. P. R.—D1354

FIG. 2.—SLOPE COURSE OF LATERAL DREDGED CHANNEL NO. 2, COURSE B, NEAR FORT PIERCE, FLA., 1917. (SEE TABLE NO. 6.)

downstream from the gauging station. At the time that the measurements were made during 1916 the cross section of the channel was fairly uniform, except for the lowest stage (Plate XIX, fig. 2; and figs. 11 *C* and 12 *E*). The side slopes were rather irregular. The soil in the bottom of the channel was largely clay, and on the side slopes a very hard clay. There were some water weeds in the bottom of the channel and a growth of grass and lilies near the water edge at low stage. As would be expected, a high value of *n* was obtained (Table 6) for the lowest stage, due to the vegetation and to the rough condition and abrupt variations in cross section. The other values were also rather high, due no doubt to the irregularities and vegetation in the channel.

The channel was cleaned out and deepened with a drag-line excavator after the 1916 measurements had been made. After this work had been done, values of *n* were again determined for the channel during 1917. The upstream end of the 1917 course was located 160 feet farther upstream than that of the 1916 course. The course was straight and was 900 feet long. The cross section of the channel was fairly uniform, there being no very abrupt variations (fig. 12 *F*), and was in rather good condition except for irregularities in the bottoms and some weeds that the excavating machine did not remove. Comparing the values of *n* obtained during 1917 with those for 1916, it is seen that much lower values were obtained after the channel was cleaned out and deepened.

LATERAL DREDGED CHANNEL NO. 2, NEAR FORT PIERCE.

Values of *n* were determined for two courses of this lateral channel, course *A* being in good condition and course *B* in very poor condition. The gaugings were made from suspension foot bridges. A good idea as to the shape, condition, and uniformity of these channels can be obtained from Plate XX, and figures 11 *D*, 11 *E*, 12 *G*, and 12 *H*.

Course *A* was straight and was 503 feet long; it was located at a place where the channel passed through a ridge of hard clay. The side slopes of the channel were probably about as they were left by the excavating machine and showed no evidence of erosion or sloughing off. As may be seen from Plate XX, figure 1, there was some vegetation in the channel. The rather high values of *n* obtained for this channel were probably due to the presence of vegetation and to the abrupt variations in cross section.

Course *B* was straight and was 500 feet in length. This course was located in one of the so-called sand ponds. The soil is sandy and easily eroded. The banks have been washed in, and considerable material had been deposited in the channel. The cross section was very broad and shallow as compared with that for course *A* (fig. 11 *E*). There was considerable vegetation, covering the entire perimeter of the channel, as may be seen by referring to Plate XX, figure 2. The values of n obtained are very high, due no doubt principally to the presence of vegetation.

Unusual care was exercised in making the slope measurements and gaugings for both courses of channel. The slope for course *A* was very small and required precise measurements to secure reliable results.

DISCUSSION OF FLORIDA EXPERIMENTS.

Owing to the fact that the slopes for channels in this section of the country are quite small, the velocities are necessarily low. As a result, the channels are subject to silting and to the rapid growth of vegetation. Unless channels in this section are to be carefully maintained, it can be seen from the results of the experiments as given in Table 6 that a comparatively high value of n should be used in their design.

VARIATION OF n WITH STAGE IN CHANNEL.

The results of these experiments show that generally the value of n decreases as the stage in the channel increases. This was pointed out in an article in the Engineering News, February 24, 1916, by R. E. Horton, as being true for natural river channels and was attributed to the fact that:

> In determining the coefficients of roughness in natural river channels the entire cross section as determined by soundings is taken into account, whereas if the cross section is irregular there may be pockets or holes in the bed of the stream containing slack water at lower stages, so that the full area of section is not effective. Similarly at low stages of the stream there is likely to be more or less fall that is not effective as slope and that does not contribute to producing velocity.

While the above is also generally true for dredged channels, yet these experiments show a great many exceptions, one of which is that of Mud Creek, where the values of n obtained were practically the same for all stages in the channel, owing to the fact that there was no appreciable amount of ineffective slope or cross-section and practically no difference in the degree of roughness of the channel for different stages (see Plate III, fig. 1 and Table 1). Another exception which shows the very reverse of the general statement above is that of Bogue Phalia, where n increased for an increase of stage. This was due to the excellent condition of the lower part of the channel as compared with that of the upper part (see Plate V, fig. 1, and Table 2).

APPLICATION OF RESULTS.

It is impossible to describe with absolute accuracy the conditions existing in a channel, such as degree of regularity, amount and nature of obstructions and vegetation, and uniformity of cross section.

Consequently it is impossible to formulate definite rules to govern one in choosing the proper value of n for any particular channel. It is believed that views, together with complete descriptions of channels for which the values of n have been determined, afford the best means of arriving at the proper value of n to employ for any particular channel. This applies especially to existing channels where it is desired to ascertain the capacity.

In order to determine the capacity of a proposed dredged channel it is necessary to assume anticipated conditions of channel. As is readily seen from the results of these experiments, values of n for dredged channels vary greatly, depending principally upon irregularities of side slopes and cross section due to erosion, caving banks, or faulty construction; upon obstructions and growth in the channel due to a lack of maintenance; and, under certain conditions, upon the effect of a lining of silt in the channel. In most cases where erosion takes place in a newly-constructed and well-finished dredged channel, the roughness coefficient increases, but the capacity of the channel as a rule also increases, since the enlarged cross section more than offsets the effect of the increased roughness coefficient. In some instances practically no difference in capacity in a newly-dredged channel may result due to erosion, after a certain amount of erosion has taken place, as was found to be the case for the experiments conducted at Trenton, Tenn. (see Table 3).

CONCLUSIONS.

A careful study of the results of these experiments suggests the following conclusions:

(1) That a deposit of slick, slimy silt on the sides and bottom of a channel greatly reduces frictional resistance to flow (see results for Allen and Willow Creeks in Table 4).

(2) That the clearing of perennial growth from a channel will greatly increase its capacity (see results for Old Town Creek in Table 1).

(3) That the growth of grass and weeds in a channel during the summer greatly decreases its capacity (see results of experiments for North Carolina in Table 5).

(4) That the accumulation of drift, trees, logs and other obstructions in a channel greatly decreases its capacity (see results for South Forked Deer River Channel at Campbell's levee in Table 3).

(5) That after a certain amount of erosion has taken place in a channel, further erosion does not necessarily increase the roughness of the perimeter (see results for North Forked Deer River in Table 3).

(6) That the roughness coefficient n is appreciably higher for a roughly dredged channel than for a smoothly dredged one (see results for the South Forked Deer River at Jackson and Roberts, in Table 3).

(7) That ordinarily a dredged channel quickly deteriorates in hydraulic efficiency unless systematically maintained (see results for Old Town Creek in Table 1).

(8) That abrupt variations in cross section play an important part in reducing the hydraulic efficiency of a channel (compare figs. 2, 4, 6, 8, 10, and 12 with values of *n* in the tables).

(9) That generally, in designing a proposed dredged channel, a value of *n* of 0.030 should be used if the channel is to be smoothly dredged, and of 0.035 if roughly dredged. If the above values are used the channels should be carefully maintained, and if not to be so maintained a value of *n* should be selected in accordance with the worst anticipated conditions for the channel. However, if it is known that such conditions will obtain as were found for some of the channels in western Iowa, a somewhat lower value of *n* may be used, depending upon the anticipated conditions of the channel.

(10) That in computing the capacity of an existing channel the value of *n* chosen should whenever possible be based upon a comparison of the conditions in the existing channel with the conditions of channels for which values of *n* have been determined; such comparison being made, if not by actual inspection, at least with the aid of careful descriptions and views of the investigated channels.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 833

Contribution from the Bureau of Entomology.
L. O. HOWARD, Chief.

Washington, D. C. May 31, 1920

CHRYSANTHEMUM MIDGE.[1]

By C. A. Weigel and H. L. Sanford, *Collaborators, Tropical and Subtropical Fruit Insect Investigations.*

CONTENTS.

GENERAL DESCRIPTION.

The chrysanthemum midge, *Diarthronomyia hypogaea* (F. Löw), is a European insect which gained entrance into the United States a few years ago and since then has been reported as injurious from widely separated localities in this country and Canada.

When chrysanthemums are infested by this midge, the attention of the casual observer is most likely to be drawn to the presence of galls. These galls occur on the leaf, stem, or flower head of the chrysanthemum plant. (See Pl. I, B and C.) After the larvæ hatch from the orange-colored eggs, which are deposited by the adult female on the surface of tender tips and new growth, they bore their way into the tissues, thereby giving rise to the galls.

The galls are cone-shaped and generally project obliquely from the surface. The length of the gall when fully developed is about one-

[1] The account of the chrysanthemum midge contained in this bulletin is the result of an investigation which was undertaken with the intention of providing further data on the life history and habits of this insect, as well as more satisfactory means of control. The preliminary life-history studies which were started in February, 1917, by A. D. Borden, of the Bureau of Entomology, were subsequently taken up by H. F. Dietz, of the Federal Horticultural Board. Further studies on life history and control were inaugurated and carried to completion by the writers as a result of the many inquiries for advice as well as the outbreaks reported during the chrysanthemum season of 1918 and the spring of 1919. During the entire period the work has been under the constant supervision of E. R. Sasscer, chief inspector of the Federal Horticultural Board and collaborator of the Bureau of Entomology.

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twelfth of an inch. When the leaf is affected, the galls usually occur on the upper surface. In such cases a slight swelling often may be observed on the opposite or under side of the leaf. Growth and development of both larva and pupa take place within this gall. When the pupa is fully developed it pushes itself out of the gall, still inclosed in the pupal skin. The latter then splits down the middle of the head and back to allow the adult to emerge. (See Pl. II, C.)

In the adult stage the midge is a fragile two-winged fly, one-fourteenth inch in length. The abdomen of the male is yellowish orange, while that of the female is reddish orange. The adult on emerging leaves its pupal skin protruding from the opening of the empty gall. (See Pl. II, A.) As shown in the life-history studies, the adults emerge after midnight and egg-laying takes place early in the morning.

HISTORICAL.

In 1870, E. Perris (1, p. 177)[1] is recorded as having observed cecidomyiid larvæ on *Leucanthemum vulgare*. Six years later J. E. Von Bergenstamm and P. Löw (2) also recorded larvæ which in all probability were cecidomyiid, as they were found attacking the young leaves of *Chrysanthemum leucanthemum* (*Leucanthemum vulgare*.) In August, 1875, E. Berroyer collected specimens in Raxalpa, a group of the Eastern Alps of Austria-Hungary, at an elevation of 5,000 feet above sea level. These specimens, which consisted of subterranean galls, and two adult male midges, were submitted to Franz Löw (3) by Von Bergenstamm. Franz Löw made the original description in 1885, which freely translated is as follows:

Male: Antennæ 2–14 jointed. Peduncle shorter than the segments. Terminal segment with two whorls of stout setæ. Wings cloudy white. All veins, also costal vein white. Second parallel vein straight, disappearing in the apex of the wings. First branch of the third parallel vein so weak that it is not visible, unless under best of light and high power, but the wing fold on the other hand is very plainly discernible. Halteres white. Legs with closely adhering hairs, also appearing white.

Larva: The still unknown larva causes galls on the underground parts of the stem of *Chrysanthemum atratum* Jacq., in which their complete transformation takes place. In each are also found several larvæ, each larva occupying one cell for itself.

Pupa: The pupa has (like the pupa of the Asphondylia species) three pairs of horns, but on the other hand, lacks the rows of delicate horns found on the dorsal surface of abdominal segments of the Asphondylia species.

The two cephalic horns are very large, widely separated, slender, quite pointed and with the point somewhat recurved. The horns of both other pairs are very small, alike in size and structure, pointed and also with the point somewhat recurved. They occur in such a manner that a horn is located above and below each eye of the pupa; consequently, the horns of one pair are widely separated from each other. In the cells of the galls in which pupation of the larva takes place, the pupæ are so situated that the head points to the periphery of the gall.

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[1] Numbers in parentheses refer to "Literature cited," p. 23.

Galls: They occur, three or four in number, at the extremity of the upper and lower surfaces of the stem of the *Chrysanthemum atratum* Jacq., which is irregularly rounded, varying in size from a large hemp seed to a large pea. Outside naked, consisting of a fleshy homogeneous mass in which occur small, elongated cells or chambers each being inhabited by a larva.

Distribution: On Raxalpa about 5,000 feet above sea level. (E. Berroyer.)

From this date, until it was first reported by Felt in the United States, frequent references are found in literature relating to its occurrence and synonymy. Among these may be listed the following: Rübsaamen (4, p. 375), Kieffer (5, p. 21), (6), (7, p. 351, 353), (13), Baldrati (8, p. 40–41), Kertész (9, p. 69), Houard (11), and Küster (12, p. 77, 274).

On March 26, 1915, R. H. Pettit of the Michigan Agricultural College had his attention called to the existence of an infestation occurring in large chrysanthemum houses at Adrian, Mich. Specimens were submitted to E. P. Felt (14), State entomologist of New York, who in April of that year determined it as the chrysanthemum midge, *Diarthronomyia hypogaea* (F. Löw). In 1916 A. Gibson (21) reported the occurrence of the midge at Ottawa, Canada. Subsequently, reports of its occurrence have been received from widely separated points, both in the United States and Canada. According to California florists, this pest has been present in that State for about 15 years.

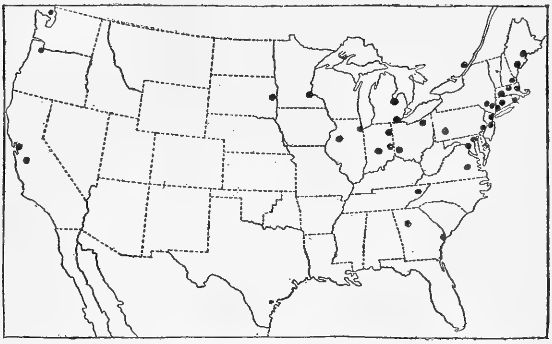


FIG. 1.—Map showing distribution of the chrysanthemum midge in the United States and Canada.

DISTRIBUTION IN THE UNITED STATES AND CANADA.

To date, the midge has been reported from California, Connecticut, Delaware, the District of Columbia, Georgia, Illinois, Indiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Tennessee, and Virginia, as well as from Ottawa and Victoria, in Canada.

Since the first records of its occurrence and seriousness were reported from the Middle West it would appear that the distribution of infested plants from this region was the source of its further spread to the other sections of the United States and Canada.

Its distribution, as indicated on the accompanying map (fig. 1), is almost wholly confined to the larger chrysanthemum-growing regions of the United States, which include the areas surrounding the Great

Lakes and the northern and central Atlantic seaboard. On the Pacific coast it is reported from California and Oregon, and its presence has been confirmed in South Dakota, Tennessee, and Georgia. Doubtless a careful survey would locate many additional isolated infestations which have not been brought to the attention of State or Federal entomologists.

VARIETIES AFFECTED.

While the chrysanthemum midge has been recorded from central and southern Europe as seriously injuring the common white or oxeye daisy (*Chrysanthemum leucanthemum*), as well as *C. corymbosum*, *C. atratum*, *C. japonicum*, and *C. myconis* (11), its depredations in North America are confined to practically all of the commercial chrysanthemums, both the single and pompon varieties. The first infestation in this country was reported on the variety Mistletoe, and according to Felt (14, 15, 16) this variety appears to be very susceptible to the attacks of the midge.

Although several attempts have been made to infest the Shasta daisy and the common field daisy, *C. leucanthemum*, it has not been possible to get the ovipositing female to lay eggs on them. This is of much importance, for should the infestation spread to this common weed, there would be great difficulty in eradicating this pest.

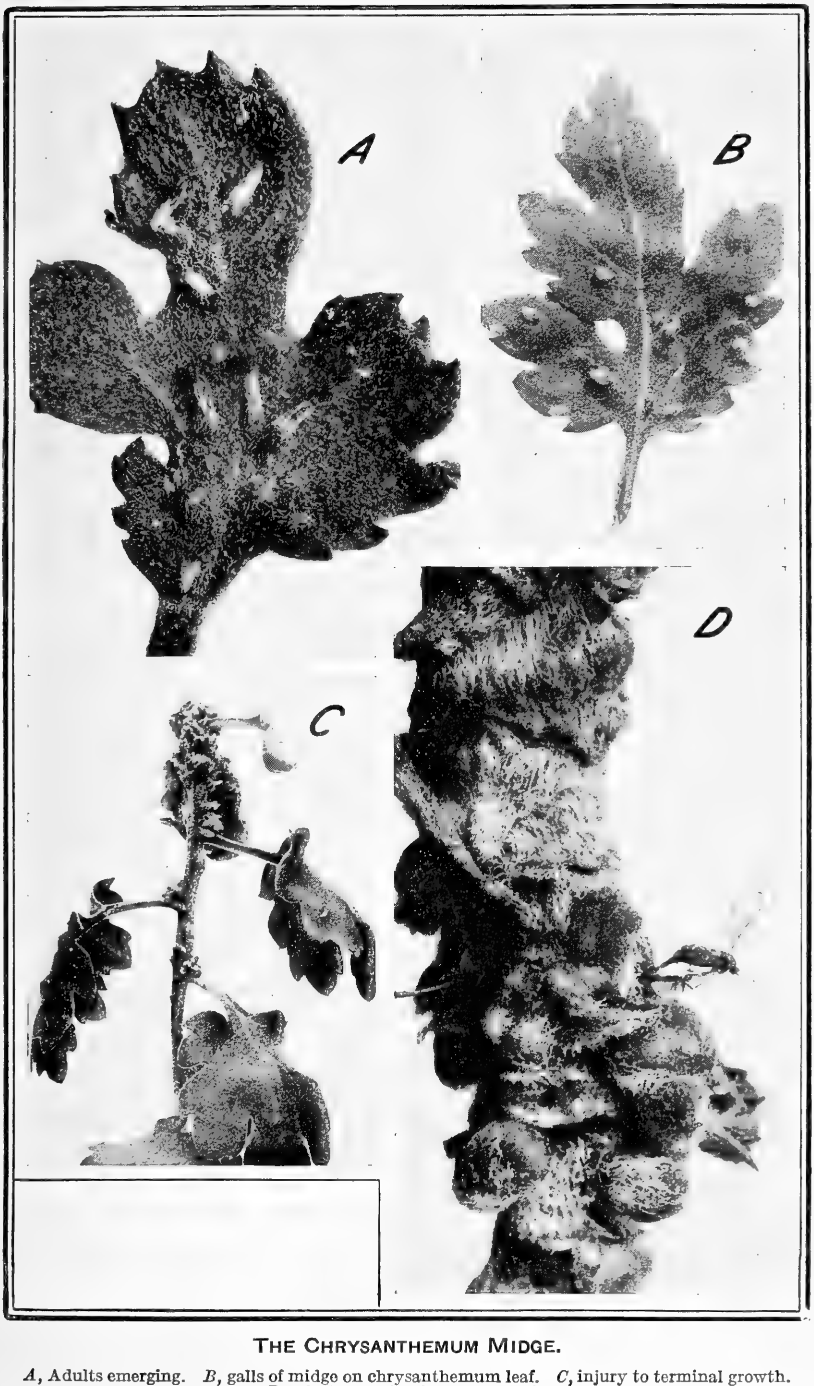
A. Gibson lists the following varieties as being fairly free from injury: Bob Pulling, Gertrude Peers, Daily Mail, Oconta, Mrs. G. C. Kelly, W. Wood Mason, F. T. Quilleton, and E. T. Quittington. All the above varieties are the blended product of *C. indicum* and *C. morifolium*, both of which grow wild in China and Japan. He reports the following varieties as being practically ruined: Smith's Advance, Ivory, Bonnaffon, Wm. Turner, Western King, and Englehart.

Observations made by H. F. Dietz in the Middle West showed that the Wm. Turner variety had lost all the crown buds. In case of a thick infestation on the variety Dr. Enguehard all of the plants had to be discarded early in the season; also all Chadwick varieties, as well as Elberon, Major Bonnaffon, and Golden Mensa. The varieties which seemed to be least injured were Golden Age, Harvard, and White Bonnaffon.

In some of the greenhouses of the District of Columbia during the season of 1918-1919 such varieties as Mensa, William Turner, and the white and yellow Bonnaffon were completely ruined on account of the severe infestation.

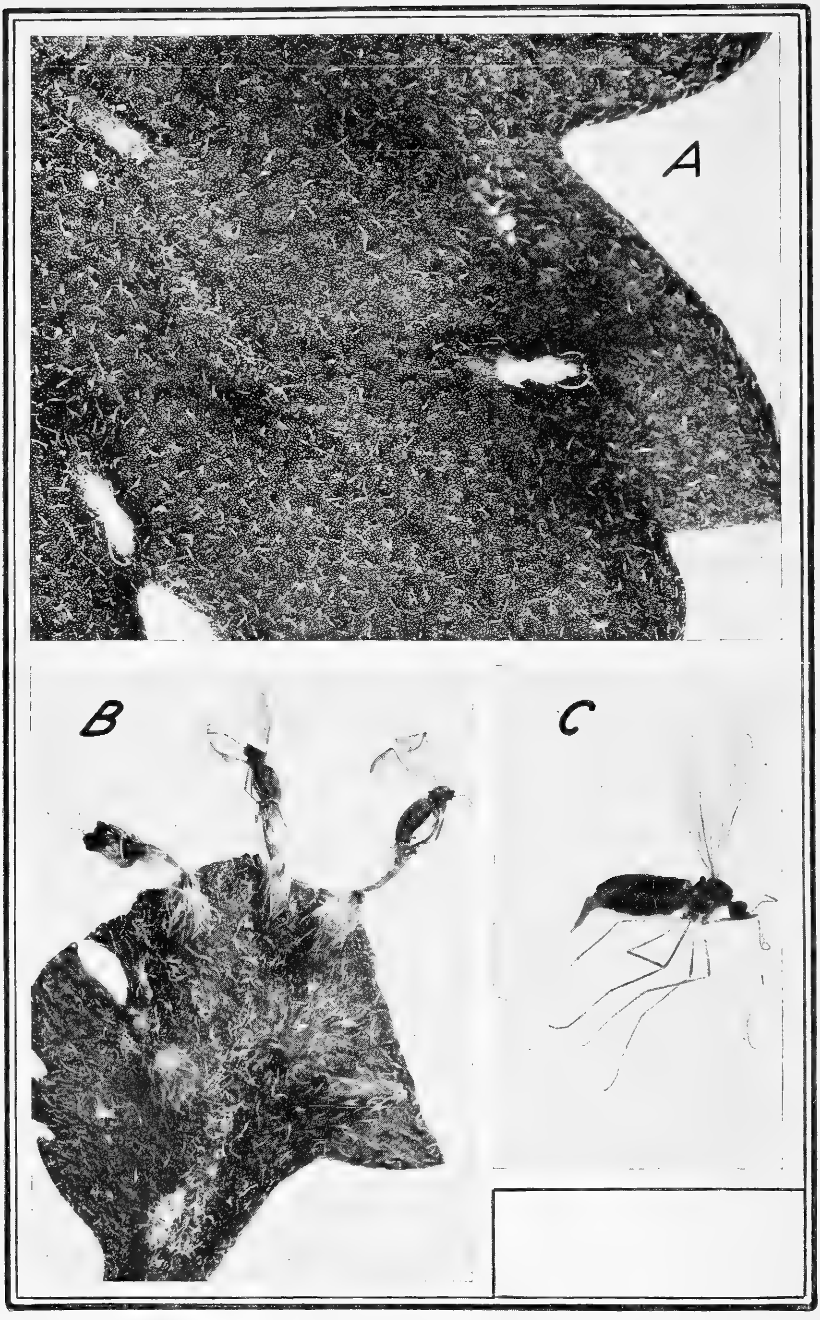
ECONOMIC IMPORTANCE.

Although a comparatively recent introduction this insect now seems to be firmly established in the United States and is one of the most important pests to be reckoned with by chrysanthemum growers.



THE CHRYSANTHEMUM MIDGE.

A, Adults emerging. *B*, galls of midge on chrysanthemum leaf. *C*, injury to terminal growth. *D*, adult emerging from stem gall.



THE CHRYSANTHEMUM MIDGE.

A, Empty pupal skins protruding from galls after emergence of adults. *B*, adults killed while emerging as a result of being sprayed with nicotine sulphate. *C*, adult female midge.

While it is primarily a greenhouse pest, A. Gibson, in August, 1915, found it occurring on both greenhouse and outdoor plants at Ottawa, Canada. Well-developed galls on the newly unfolded leaves were found by the authors, March 26, 1919, on hardy chrysanthemums which had been grown out of doors all winter at the Arlington Farm, Rosslyn, Va. A careful inspection of the entire stock revealed the fact that the insects had wintered over on these plants in the immature stages, probably as either larvæ or pupæ within the galls. Inasmuch as there were many empty galls present on the old dead and dried leaves of the previous season's growth, it was evident that this was an infestation of long standing. On April 11, many adults were found entangled in webbing spun by spiders among the developing new tip growth. These emerged from the above mentioned galls.

The first severe infestation of the midge brought to the attention of the Bureau of Entomology was on chrysanthemums in greenhouses at Philadelphia, April, 1917. The entire stock was infested, causing a total loss to the grower. During the same year other florists reported a total loss of their stock of chrysanthemums valued at several thousand dollars. Even in the case of a light infestation the foliage is practically valueless for commercial purposes, and in the case of a heavy infestation the growth is completely arrested. (See Pl. I, C.)

Owing to numerous reports of injury by the chrysanthemum midge in the States of Indiana, Illinois, and Michigan, H. F. Dietz conducted a survey in this territory during the months of November and December, 1918, for the purpose of ascertaining the exact amount of damage occasioned by this pest. From the data gathered, this general locality proved to be one of the centers from which the pest was being distributed over the United States. Greenhouses of 33 florists were visited, including some of the largest growers and distributors in this country. It was evident that if serious pests were established in this region, it would be only a matter of a year or two before such insects would be widely scattered. This is exactly what has happened in the case of the chrysanthemum midge. This pest was found established in 8 of 33 places visited.

Serious injury to infested plants was noted. For example, no plants of the variety Dr. Enguehard came into flower, on account of their dwarfed, knotted, and knarled condition, with the result that the new central stem did not form. Moreover, other varieties, including Wm. Turner, were attacked just at the time the crown buds were "setting," causing these flowers to become distorted. As a result, the flowers are not borne upright as normal flowers should be. Such evidence may be taken as an indication of the presence of the midge, even though the galls may not be numerous enough to attract attention.

From these data it is apparent that the insect is a serious pest, especially in cases where growers require from 50,000 to 100,000 plants for their own use and five to ten times this number to fill annual orders for shipment.

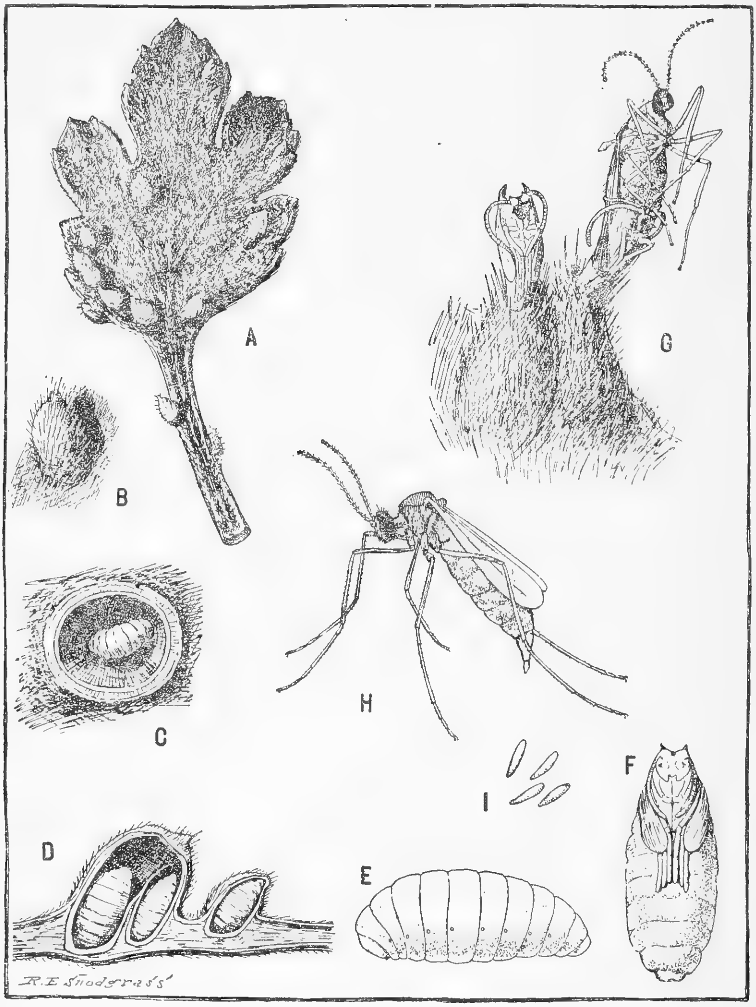


FIG. 2.—The chrysanthemum midge: *A*, Leaf covered with galls; *B*, a single gall, more enlarged; *C*, gall cut open from above, showing young larva within; *D*, two galls cut in vertical section; *E*, larva, enlarged about 13 times; *F*, pupa; *G*, fly emerging from a gall on right, discarded pupal skin remaining in opening of gall on left; *H*, adult female fly, enlarged about 13 times; *I*, eggs. (9th Ann. Rept. State Ent. Ind.)

TECHNICAL DESCRIPTION.[1]

Egg [fig. 2, I].—Reddish orange, length .15 mm., diameter .03 mm., the extremities narrowly rounded.

Gall [fig. 2, A, B, C, D, G].—Conical swelling projecting obliquely from the surface. Size about 2 mm. in length. Color, generally green. Reddish green when growing outside and depending on variety affected. Tips appear dried out and grayish at

[1] Technical description of egg, larva, pupa, male, and female taken from Felt (20).

times. Hairs on tip in superabundance. Occurring on both leaf surfaces, stem and flower head.

Larva [fig. 2, C, E].—Length 1 mm., yellowish or yellowish orange when full grown, moderately stout, the extremities rounded; segmentation distinct and the skin smooth.

Pupa [fig. 2, F].—Length 1.25 mm., stout, narrowly oval, the cephalic horns distinct, conical, the thorax yellowish orange, the wing pads fuscous in pupæ nearly ready to transform, the leg cases dark yellowish brown, the abdomen a variable orange, narrowly rounded apically.

Male.—Length 1.75 mm. Antennæ nearly as long as the body, sparsely haired, fuscous yellowish; 17 or 18 segments, the fifth with a stem about three-fourths the length of the subcylindric basal enlargement, which latter has a length about twice its diameter and a rather thick subbasal whorl of long, stout setae; terminal segment variable, usually somewhat reduced, irregular, elongate, ovate. Palpi: The first segment subquadrate, the second narrowly oval. Mesonotum dark brown, the submedian lines yellowish. Scutellum and postscutellum fuscous yellowish, the abdomen mostly a pale yellowish orange. Wings hyaline, costa light straw, halteres yellowish transparent. Legs a pale straw, the pulvilli a little longer than the long, slender claws, the latter with a long, slender tooth basally. Genitalia; basal clasp segment moderately long, stout; terminal clasp segment short, stout, with a distinct spur; dorsal plate short deeply and roundly emarginate, the lobes short, broad, obliquely truncate apically; ventral plate short, deeply and roundly emarginate, the lobes rather long and tapering to a narrowly rounded apex.

Female [fig. 2, H].—Length 1.75 mm. Antennæ extending to the third abdominal segment, sparsely haired, fuscous yellowish; 16 or 17 segments, the fifth with a stem about one-third the length of the cylindric basal enlargement, which latter has a length a little over twice its diameter; terminal segment reduced, sometimes compound and tapering to a narrowly rounded apex. Palpi: The first segment subquadrate, the second subconical and with a length a little greater than the first. Mesonotum fuscous brown, the submedian lines, the posterior median area, the scutellum and postscutellum mostly fuscous yellowish, the apex of the scutellum narrowly fuscous. Abdomen reddish orange, apically fuscous yellowish, the ovipositor about one-half the length of the body; terminal lobes short, broad, broadly rounded and sparsely setose apically. Other characters practically as in the male.

LIFE HISTORY AND HABITS.

ADULT STAGE.

The adult female shows a marked preference to lay eggs in the buds, or in the tissues just unfolding from the buds. Serious injury to the host results from this habit, and the commercial value of the plant is greatly reduced, if not entirely eliminated.

Emergence of adult.—On March 26, 1919, H. L. Sanford observed the emergence of a female at 1.09 a. m. On the following night observations by C. A. Weigel taken at intervals varying from 15 to 20 minutes apart beginning at 12.30 a. m., and ending at 5.45 a. m., showed the emergences as follows: At 1 a. m., 1 female; at 4 a. m., 1 male; at 4.02 a. m., 4 females, 3 males. In addition the following observations were recorded: When the female emerges the body is pushed out of the gall for approximately three-fourths its length. The wings at this time appear as dark gray or black club-like appendages. The antennæ are moved about in a very active manner. The legs, which are at first folded parallel to the body, are thrust outward and immediately begin movement. The body is swayed back and forth with contractions of the abdomen which is still inserted within the gall, the latter acting as a fulcrum. In about two minutes from the time at which the adult is first seen to break through the gall, the entire body is freed from its pupal skin. The pupal skin remains protruding from the empty gall case, as seen in Plate II, A. With a convulsive motion the insect gains a foothold by thrusting out the legs and was observed almost immediately to travel rapidly to the underside of the leaf, assuming a position at right angles to the leaf surface. In this hanging position, which is characteristic of the adult female, it remained over an hour, occasionally fluttering its wings. Upon being disturbed it made a very short flight and returned to the underside of the same leaf. Evidently the above-described position is assumed to allow for drying and inflation of the wings.

Mating.—A male was observed to fertilize a female approximately 3 minutes after the emergence of the latter, the entire operation taking 10 seconds. One male was observed to fertilize three females in rapid succession.

TABLE I.—*Longevity of adults and date of oviposition.*

Cage.	Adult emerged.	Number.		Oviposition.	Adults died.		Length of life.
		Male.	Female.		Male.	Female.	
	1917.						Days.
1	Apr. 2, a. m.	0	1	None		Apr. 5, a. m.	3
2	Apr. 5, a. m.	0	2	...do		Apr. 8, a. m.	3
3	Apr. 6, a. m.	3	0	...do	Apr. 6, p. m., 2		½
					Apr. 7, a. m., 1		1
4	Apr. 10, a. m.	2	2	Apr. 10	Apr. 10, p. m.		½
						Apr. 11, a. m.	1
5	...do	2	2	None	Apr. 10, p. m.		½
						Apr. 12, a. m.	[1] 2
6	Apr. 11, a. m.	0	1	...do		Apr. 13, p. m.	[1] 2½
7	Apr. 12, a. m.	0	2	...do		...do	1½
						Apr. 14, a. m.	2
8	Apr. 13, a. m.	3	1	Apr. 13	Apr. 13, p. m., 2		½
						Apr. 14, a. m.	[1] 1
					Apr. 14, a. m.		1¼
9	...do	1	1	...do	Apr. 13, p. m.		½
						Apr. 14, a. m.	1¼
10	...do	0	1	None		Apr. 17, a. m.	[1] 4
11	Apr. 17, a. m.	0	1	...do		Apr. 20, a. m.	3
	1918.						
12	Jan. 31, a. m.	0	2	...do		Feb. 1, a. m.	1
13	...do	0	2	Jan. 31		Feb. 2, a. m.	2
14	...do	0	1	...do		Feb. 1, a. m.	1
15	...do	1	2	...do	Lost	Feb. 2, a. m.	2
16	Feb. 1, a. m.	0	2	Feb. 1		...do	1
17	Feb. 11, a. m.	0	2	Feb. 11		Feb. 13, a. m.	2
18	Mar. 14, a. m.	1	0		Mar. 15, a. m.		1
19	July 10, a. m.	0	1	July 10		July 11, a. m.	1
20	July 17, a. m.	1	1		July 17, p. m.		½
						July 18, a. m.	1
21	July 18, a. m.	0	1			July 20, a. m.	2
22	July 19, a. m.	1	0		July 20, a. m.		1
23	Aug. 2, a. m.	2	0		Aug. 3, a. m.		1
24	Aug. 3, a. m.	0	1	Aug. 3		Aug. 3, a. m.	½
25	Aug. 5, a. m.	0	1	Aug. 5		Aug. 6, a. m.	1
26	Sept. 2, a. m.	1	0		Sept. 2, p. m.		½

[1] Female not fertilized and did not deposit eggs.

Longevity of adults.—In the life-history studies it was found that males usually live less than 12 hours, while the females live from 2 to 3 days, in captivity and when not mated. Mated females probably do not live over 24 hours. In the case of three males which were seen to emerge after 1 a. m., all were found dead at 5.45 a. m. These results are given in detail in Table I.

Activity.—The males are not often seen on the wing, as they die shortly after mating, which takes place during the early morning hours, almost directly after emergence. When on the wing, however, they are very active. The females, while generally rather sluggish, may show great activity at times, especially in the early morning and just prior to egg deposition. Dietz observed that on cool days when the temperature was 50° F. in the daytime, and cooler at night, the adult females were exceedingly active. Emergence records taken on many cages show that there are a somewhat larger number of females than males, the actual count being 464 females to 365 males.

Egg deposition.—The female when laying eggs keeps her legs at equal distances apart and the ovipositor held at right angles to the rest of the body, beginning probably at the third or fourth abdominal segment. If not disturbed she acts with great precision. On one occasion a female was carefully observed during two operations, laying 34 and 19 eggs respectively. The first oviposition period lasted exactly 3 minutes and 30 seconds, the second only 1 minute and 20 seconds. An interval of only 10 seconds elapsed between the operations. The tip of the long flexible ovipositor is thrust between the pubescent hairs of the young terminal growth and pressed down firmly on the surface. During deposition the eggs may be seen moving down the tube with great rapidity, accompanied by slight contractions of the ovipositor. Because of its darker color, the egg is plainly visible through the walls of the ovipositor. The number laid at one time, according to Table II on page 10, varies from 5 to 135, with an average of 32. Guyton (31) found that "the number deposited by each female is from 80 to 150." The eggs are usually placed in irregular masses, although they may be placed in strings or chains. During the whole operation the ovipositor is thrust around in a very nervous manner. At times when the female moves slightly about, the body is not straightened out but dragged along to the new place of deposition, in the original bent position. Although egg-laying may take place up to and later than 4.30 p. m., the maximum egg-laying occurs from the early morning hours up to midday. The midges prefer to lay eggs on the terminal growth of the plant on which they emerge, and particularly on the unfurling tip growth. This is true even in cases where the terminal growth has been badly distorted previously as a result of their work. Females have been noted to return to such plants from which they have emerged and deposit eggs thereon. Even though they were repeatedly disturbed, they would return quickly and continue deposition. On many occasions it was found that when these young tips were separated and examined, the eggs would be present in greater numbers between the folds of the new tissue than on the neighboring exposed surfaces.

Incubation.—Observations, as given in Table II, show that the incubation period varies from 3 to 16 days. The time of incubation may be affected by the season of the year.

TABLE II.—*Length of egg period.*

Cage.	Host plant.	Deposited.	Hatched.	Length.	Number deposited.
		1917.		*Days.*	
1	October Frost	Apr. 2	Apr. 7	5	No records.
2	Snow Queen	Apr. 3	Apr. 8	5	Do.
3	Silver Wedding	Apr. 4	Apr. 9	5	Do.
4	Golden Glow	Apr. 5	Apr. 10	5	Do.
5	Harvard	Apr. 6	Apr. 11	5	Do.
6	Esanath	Apr. 7	Apr. 12	5	Do.
7	Snow Queen	Apr. 10	Apr. 15	5	Do.
8	Monrovia	Apr. 12	Apr. 17	5	Do.
9	Martha Saunders	Apr. 13	Apr. 18	5	Do.
10	Gold Chadwick	Apr. 16	Apr. 21	5	Do.
11	Esanath	Apr. 17	Apr. 22	5	Do.
12	Monrovia	Apr. 20	Apr. 25	5	Do.
		1918.			
13	Silver Wedding	Jan. 31, Feb. 1	Feb. 9	8–9	Do.
14	do	do	Feb. 7	6	Do.
15	do	Feb. 2	do	5	25 eggs.
16	Dr. Enguehard	Feb. 11	Feb. 15–19	4–8	No records.
17	Pompon	Feb. 28	Mar. 6	6	Do.
18	Silver Wedding	Mar. 1	Mar. 6–10	5–9	Do.
19	Dr. Enguehard	Mar. 4	Mar. 9	5	Do.
20	Dr. Pool	Aug. 26	Sept. 6	11	34 eggs.
21	Mrs. R. N. McLuckie	Aug. 27	Aug. 30	3	19 eggs.
22	Margaret Bissett	Aug. 29	Sept. 4–14	6–16	5 eggs.
23	Silver Wedding	do	Sept. 6	8	20 eggs.
24	Mensa	do	Sept. 6–14	8–16	24 eggs.
25	Silver Wedding	Sept. 5	Sept. 10–14	5–9	25 eggs.
26	Golden Wedding	Sept. 21	Sept. 24	3	135 eggs.

Development.—The development of the larva within the egg can be made out easily. In the newly laid egg the nucleus, which is reddish in color, is rather central, but shows a slight tendency to be located toward the anterior end. There are approximately 18 yolk bodies present which are arranged in a row of 9 on each side. The rows do not extend quite to the posterior end of the egg. As development proceeds the red pigment or nucleus moves to one side of the egg, which later is apparently the ventral surface. In the meantime the yolk bodies collect in a mass near the nucleus. At each end the small air spaces, which at first are relatively small, later become much increased in size. The segmentation then begins to appear, with a simultaneous contraction of the entire contents. A redistribution of the yolk then takes place, an equal portion being present in each segment. At this stage the pigment takes up a posterior position. Finally the complete outline of the larva is visible through the shell. At this stage the darker head and mouth parts can be seen, and the previous yolk material appears as a chainlike formation which extends from the anterior to the posterior end throughout the entire inner or central portion of the body. Distinct segmentation is now clearly visible.

Hatching.—Borden observed the larva when hatching to break from the eggshell by a small cap at one end. Complete development of the larva and pupa takes place within the gall.

LARVAL AND PUPAL STAGES.

The larva or maggot upon hatching moves about on the surface among the plant hairs for a period of from 1 to 3 days, preparatory to boring into the tissue. It varies in color from a transparent white to pale orange when seen with the aid of a binocular just after boring beneath the epidermis. On February 2, 1918, H. F. Dietz observed larvæ, which hatched from eggs laid four days previously, boring into tissue. (10× eyepiece, 24 mm. objective, binocular.) The observations were as follows: One larva which was found half buried in the tissues of the stem was timed until it disappeared. It required 12 minutes for complete disappearance. During this period the larva moved back and forth with an irregular spiral movement, about 30 seconds being necessary for one complete movement back and forth. Several larvæ were then observed beginning to bury themselves, but the operation was interrupted and discontinued, the interruption being caused by another larva which was slowly crawling about in search of a suitable place to "dig in." One of these larvæ was observed crawling slowly about for approximately 3 minutes. The bright red pigment of the posterior third of the body is very characteristic at this particular stage.

As a result of the larva boring into the tissue, an irritation is produced which results in the production of swellings or galls on the plant containing the developing larvæ and pupæ.

No molts have been observed from the time of hatching to the time at which the larva is seen entering the tissue. The larva lies bathed in a fluid within the gall. The fully developed larva is of an orange color.

The female pupa is usually orange colored with the head, thorax, legs, and wing pads nearly black, while the male may be of a lighter or straw color. Formation of the pupa takes place about two weeks from the time the egg is hatched. It is white at first with only a slight brown tinge about the head, but later the head, thorax, wing-pads, and legs are dark brown, and the abdomen orange. The cephalic horns are distinct in the nearly mature form of the pupa.

When mature the pupa works its way out of the gall. On emergence a split is made upon the dorsal line of the head and thorax of the pupal case through which the adult issues. (Pl. I, A, D.) During emergence the adult is very active and issues very rapidly.

From the time that the larva enters the tissue to the first sign of a swelling, or gall, observations on 18 life-history cages show that a period ranging from 4 to 14 days elapsed with an average of 7 days (see fourth column of Table III). The young gall may now be readily recognized by the characteristic white spots, or slight swellings.

It takes from 21 to 46 days, with an average of 28 days, from the time at which the larva first enters the tissue until the emergence of the adult. These observations were taken from the results obtained from 18 cages during the spring of 1917 and the spring and fall of 1918, as is shown in the following table. Britton (32) found it to require from 20 to 50 days to transform within the gall.

TABLE III.—*Time required from: (a) larva entering tissue until first sign of gall; (b) larva entering tissue until emergence of adult.*

Cage.	Larva entering tissue.	First sign of gall.	Time, required (a).	Date of emergence.	Total length (b).
	1917.		Days.		Days.
1	Apr. 7-11			Apr. 29 to May 2	22
2	do			Apr. 30	[1] 21
3	do			May 1-2	23
4	do			Apr. 30 to May 2	22
	1918.				
5	Feb. 7	Feb. 13-16	7	Mar. 4	25
6	do	do	7	Mar. 4-7	26
7	Mar. 6-12	Mar. 15	6	Apr. 6-22	36
8	Mar. 6-10	do	7	Apr. 8-22	38
9	Mar. 12	Mar. 18	6	Apr. 27	[2] 46
10	do	Mar. 16	[1] 4	do	[2] 46
11	do	Mar. 18	6	Apr. 6	25
12	do	do	6		
13	Aug. 31	Sept. 9-19	[2] 14	Sept. 25	25
14	Sept. 2	Sept. 9	7	Oct. 2	30
15	Sept. 4-14	Sept. 17	8	Sept. 26 to Oct. 3	[1] 21
16	Sept. 4-11	Sept. 11	7	Sept. 27 to Oct. 2	22
17	Sept. 7-14	Sept. 14-19	6	Oct. 4	23
18	Sept. 24-25	Oct 2	8	Oct. 24 to Nov. 2	34

[1] Minimum time. [2] Maximum time.

From Table IV it is evident that the total life cycle requires from 27 to 52 days, with an average of 35 days. These data represent the results obtained from 17 life-history cages under Washington conditions. There is a constant overlapping of broods when the greatest numbers are present, namely in the spring and fall of each year. The æstivation period has been found to extend, in Maryland, Virginia, and the District of Columbia, from the early part of June to the latter part of August.

TABLE IV.—*Length of complete life cycle.*

Cage.	Eggs deposited.	Adult emerged.[1]	Length of life cycle.
	1917.		*Days.*
1	Apr. 2	Apr. 29 to May 2	27–30
2	....do	Apr. 30 to May 2	28–30
3	....do	May 1 to May 2	29–30
	1918.		
4	Feb. 1	Mar. 4	31
5	Feb. 2	Mar. 4 to Mar. 7	30–33
6	Mar. 1	Apr. 8 to Apr. 22	38–52
7	Mar. 5	Apr. 6	32
8	Mar. 6–9	Apr. 22 to Apr. 27	47–49
9	Aug. 3	Sept. 4 to Sept. 6	32–34
10	....do	Sept. 11 to Sept. 18	39–46
11	Aug. 6	Sept. 5	30
12	Aug. 27	Sept. 25 to Oct 4	29–38
13	Aug. 29	Sept. 26 to Oct 3	28–35
14	....do	Sept. 27 to Oct 2	29–34
15	....do	Oct 2	34
16	....do	Oct. 4	36
17	Sept. 21	Oct 24 to Nov 2	33–42

[1] Data given in Table I show that mated females deposit eggs on date of emergence.

In the spring of 1917, 1918, and 1919, three distinct generations were observed. The first generation started about the middle of February and the last adults of this generation emerged during the last few days of April. The second generation started about the middle of March and the last adults issued around April 30. The third generation started the latter part of April and emerged during the early part of June. In the fall of 1918 when the occurrence increased again a similar grouping of generations was evident, the first beginning about the latter part of August, and the last adults emerging during the first days of October. A second generation started about the middle and latter part of September, maturing the first days of November. The third generation was observed beginning about the middle of October and the last adults emerged about November 25.

NATURAL ENEMIES.

Felt (20), in speaking of the natural enemies of the midge, states that—

It was very likely brought to America without the normal quota of parasites and for a time at least it may prove to be a somewhat difficult insect to control, though it would seem as if the native parasites of our large and varied gall midge fauna might in time prey most successfully upon this midge.

Essig (18) mentions:

During the summer a large number of parasites were reared from infested plants and one species in particular did excellent work in the university greenhouse. The material was sent away for determination and a few observations made as follows:

Amblymerus sp. This hymenopterous parasite has been described by Mr. A. A. Girault, through the kindness of Dr. L. O. Howard, and a description is to appear elsewhere. The adults are black with yellow markings on the legs. The females vary from 1 mm. to 1.2 mm. in length, and the males are somewhat smaller. The larvæ live within the galls alongside the maggots of the gallfly, which they gradually consume. They remain within the galls until mature, when they emerge through small circular holes. This species is the most abundant during the summer months and all of the adults were reared during August, September, and October. In not a few cases as high as 80 per cent to 90 per cent of the maggots were destroyed.

Tetrastichus sp. The generic determination of this insect was made by Mr. Harry S. Smith, superintendent of the State insectary, Sacramento, Calif. It is also a small black parasite, somewhat larger than the former and easily distinguished from it by the four-jointed tarsi and other characters.

EXPERIMENTS IN CONTROL.

At the outset it must be borne in mind that it is very important that control measures should be closely related to the propagation of the stock, and moreover from the practical and economical point of view these steps should be undertaken at a period in the propagation when the plants can be severely cut back, allowing sufficient time to overcome any injury which may result from such treatment. Inasmuch as cuttings are propagated from the stock plants of the previous season, it is evident that the logical time to eradicate an infestation of long standing is immediately after the flowers have been removed. Naturally such precautions as would absolutely safeguard the grower against further spread and increase would have to be inaugurated.

An experiment conducted in one of the commercial greenhouses in the District of Columbia in which the plants had been heavily infested the previous season was carried out as follows: These heavily infested stock plants were heeled in and pruned back, and the entire portion above ground was thoroughly dusted with a mixture of equal parts of tobacco dust and air-slaked lime as often as the new growth appeared. As a result of such treatment the new growth was kept practically clean from further infestation and the plants at the same time showed a stimulated growth. The checks which were run simultaneously had all the new growth badly infested.

Occasionally it may happen that a grower's previous season's stock was clean and new material or varieties are being received in the form of cuttings or young plants from localities where the insect is known to exist. There is a possibility of introducing the midge on such stock even though no definite signs of the insect are visible. In the spring when cuttings and young plants are being exchanged, an infestation, especially in the egg or very young larval stage, will defy even the most careful and zealous inspectors. Interception made of plants harboring the eggs only can easily be overlooked by virtue of their concealed location in the still unfurled leaf bud.

A precautionary treatment should be given at the time when the plants or cuttings are taken or received and would prove of inestimable value in killing the eggs and immature stages.

The question of controlling an infestation already in the well-developed gall stage as well as the adult stage must also be considered. The control of the adult stage need not be taken up in experimental manner, in view of the known fact that such fragile flies can easily be controlled by light fumigation with hydrocyanic-acid gas or by burning tobacco papers, provided it is done at the correct time.

The preceding paragraphs clearly point out the advisability of determining the practical value of the several premises stated. Incidentally such factors must necessarily be solved independently of each other, but with the final view of either applying each separately when the case so warrants or consolidating such phases as would be most practical and consistent with commercial practices. The practical conclusions and recommendations that follow were deduced from results that are outlined and stated in the following pages.

EXPERIMENT 1.—CONTROL OF EGGS BY MEANS OF DIPPING INFESTED CUTTINGS.

Emphasis has been placed on the importance of beginning with clean cuttings in the spring. It, therefore, was found advisable to test out this point, and, if effective, such practices would be a safeguard to growers whose stock was badly infested as well as growers who had received outside material.

Three lots of six cuttings each were treated by J. L. Dietz as given in the following table. After treatment they were planted in sand. The tray, together with the plants, was then protected from further attacks by placing it under a close-mesh screen. The plants were treated September 26, and observations taken October 5 and 10 and November 1 are given in Table V.

TABLE V.—*Control of eggs by means of dipping infested cuttings.*

Experiment.	Treatment.	Observations and results.
1	40 per cent nicotine sulphate (1-500); laundry soap 1 ounce to 1 gallon; tips of cuttings dipped. Sept. 26, 1918.	Nov. 1: Eggs did not hatch; no new galls developed; 4 plants well rooted, 2 plants poorly rooted.
2	Same treatment as above, except that entire cuttings were dipped. Sept 26, 1918.	Nov. 1: Eggs did not hatch; no new galls developed, neither did original galls develop any further; 4 plants well rooted, 2 plants poorly rooted.
3	Check; no treatment	Nov. 1: Eggs hatched; 1 plant had 3 well-developed galls present; 3 plants rotted off; 3 plants were well rooted.

DISCUSSION OF RESULTS.

Comparing the results of both treated lots with those of the check, the results are fairly conclusive. On the treated plants the eggs in each case did not hatch, neither did the young galls originally present make further progress, whereas, in the case of the check, while only one plant showed definite results, it is clear that the galls developed.

The effect of such treatment on the plants is somewhat inconclusive due to the rotting off of three plants in the check. In the case of the treated plants, four survived in each lot.

EXPERIMENT 2.—CONTROL OF EGGS BY MEANS OF DIPPING ENTIRE PLANT.

The object of this experiment was practically synonymous with that of experiment 1 except that entire plants were used instead of cuttings as was the case in the previous test.

Twelve plants on which newly laid eggs were present were divided into three lots, (a), (b), and (c), of four plants each. They were then treated as follows:

(a) Four plants dipped in 40 per cent nicotine sulphate (1–500) plus laundry soap 1 ounce to 1 gallon of solution.
(b) Four plants dipped in 40 per cent nicotine sulphate (1–800) plus laundry soap 1 ounce to 1 gallon of solution.
(c) Four plants as check; no treatment.

In each case the plants were constantly protected by covering them with an ordinary lantern globe, the free end of which was screened with a double layer of cheesecloth. The first dipping was done on March 29, while subsequent dippings were done on March 31 and April 1, 3, and 8. The plan was to treat them at least every 2 or 3 days for a week or 10 days. Observations were taken frequently on the effect of the treatment both on the plants and on the eggs. These observations were continued until the close of the experiment, April 30, at which time the plants were uncovered and placed in the open greenhouse.

Results.—(*a*) Effect on plants: Slight burning was encountered with the 1–500 strength solution, but with the 1–800 solution no such trouble was evident. The check plants showed some sooty fungus which was probably due to the presence of honeydew secreted by aphids. (*b*) Effect on eggs: During the first few days the eggs showed normal development within the shell on the treated plants, but larvæ failed to hatch from them, and no galls developed. On the check plants all of the eggs hatched successfully and many galls developed to maturity.

Conclusions.—The expectations were fully confirmed by the results obtained, as was the case in experiment 1. The checks developed healthy and normal galls while in the treated plants further development was promptly arrested. From the economical point of view it is safe to say that nicotine sulphate (1–800) plus the soap will control the egg stage effectively if properly applied.

TREATMENT OF BOTH CLEAN AND INFESTED CUTTINGS.

The importance of having all new stock free and clean from the immature stages of the midge and of having the control at all times closely related to the propagation of stock has already been referred to. The above points were tested by the following experiment.

This test consisted of three parts. Lots 1 and 2 were clean cuttings, while lot 3 consisted of infested cuttings. Each lot was subdivided into three divisions or rows, namely, (a), (b), and (c). The last, (c), in each case served as a check on (a) and (b), which were the treated rows. The first treatment consisted of dipping the cuttings directly after they were taken, and the subsequent treatments consisted in spraying daily for a period of 7 days thereafter with a solution of the same strength.

Lot 1 consisting of clean cuttings to be used as a check was kept in a separate and uninfested unit for the purpose of determining the effect of such treatment on the cuttings. Lot 2 consisting of clean cuttings and lot 3 of infested cuttings were both tightly screened and placed in a propagating frame in an infested unit. In this manner it was hoped to determine the effectiveness of such treatment when both clean and infested cuttings had to be grown together.

LOT 1.

Six clean cuttings in each row.

Row (a). Nicotine sulphate (1–800) plus fish-oil soap 1 ounce to 1 gallon of solution.

Row (b). Volatile nicotine sulphate (1–800) plus fish-oil soap 1 ounce to 1 gallon of solution.

Row (c). Checks; not treated.

Results.—During the period of treatment it appeared as though all the plants were affected slightly. Row (a): The lower leaves of all the cuttings turned yellow, but 10 days after treatment was discontinued all but one cutting were in fine condition. Row (b): Even though no direct signs of burning were evident, the plants appeared sickly during the second and third treatments. Ten days after the discontinuance of the treatments the cuttings were in better condition than either (a) or (c). The check row (c) was slightly affected due to its proximity to the treated rows. Ten days after treatment was stopped only two plants were in good condition and one was poor.

The conclusion to be drawn from this test is that the method of treatment under (b) was probably the better of the two.

LOT 2.

Seven clean cuttings in each row. Placed in infested unit after first treatment.

Row (a). Nicotine sulphate 40 per cent (1–1,000) plus fish-oil soap 1 ounce to 1 gallon of solution.

Row (b). Volatile nicotine sulphate 40 per cent (1–1,000) plus fish-oil soap 1 ounce to 1 gallon of solution.

Row (c). Checks; no treatment.

Results.—Although this dosage was weaker than that used in lot 1, it affected the cuttings much more. After the second and third treatments the plants all looked wilted. Ten days after the last application all the cuttings but one in row (a) were dead. In row (b) all looked very poorly. In (c), the check row, one cutting was dead while all the remainder looked fairly healthy.

Conclusions.—It appears that the variety may have played an important part in this case. In this lot, as was so evident in the previous treatment, (a) causes injury, while (b) gives a double benefit—first, it does not cause injury; and second, it protects the plant. The midges spread to the check row (c), and two galls had adults emerge from them.

LOT 3.

Three rows of seven infested cuttings each.

Row (a). Nicotine sulphate 40 per cent (1–1,000) plus fish-oil soap 1 ounce to 1 gallon of solution.

Row (b). Volatile nicotine sulphate 40 per cent (1–1,000) plus fish-oil soap 1 ounce to 1 gallon of solution.

Row (c). Check; not treated.

Results.—This variety stood up much better than did that in lot 2.

Row (a). Slight burning evident. In fair condition 10 days after treatment.

Row (b). Only two poor plants; no burning. All recovered 10 days after treatment.

Row (c). All plants in good condition, slightly better than row (b). No galls developed.

Either treatment (a) or (b) might be used successfully.

FINAL CONCLUSIONS.

Comparing the three lots with one another the following conclusions may be drawn: The practices described injure the cuttings only slightly and afford reasonable protection from the midges.

EXPERIMENTS ON CONTROL OF GALL STAGE.

The final consideration concerns the control of the gall stage, which is the hardest to combat. Owing to the habit of the larvæ of burrowing into the plant tissues, the chief difficulty is that most spraying mixtures when applied to foliage fail to exert their toxic properties against the insects contained therein. This may be accounted for by the resistance of the leaf structures to penetration by insecticides.

EXPERIMENT 1.

A preliminary experiment, in which was used 1 part 40 per cent nicotine sulphate to 250, 500, and 1,000 parts water, respectively, to which fish-oil soap or laundry soap at rate of 1 ounce to each gallon of solution was added, showed conclusively that one application was entirely ineffective in controlling the gall stage. The data which were taken at various intervals showed that the adults emerged successfully and continually. Hence, it was decided to test out the efficiency of several applications when made two and three days apart. The test is given in the next paragraph.

EXPERIMENT 2.

In the treated lots five plants were used for (a), (b), (e), and (f), and six plants for (c) and (d) for each test. The plants used had been growing in pots. Only two plants were used in both checks. The dipping was done as indicated every two or three days. Observations were taken daily.

TABLE VI.—*Results of experiment 2.*

Started.	Closed.	Treatment.	Total emerged.	Total killed.	Percentage of efficiency.	Remarks and conclusions.
1919.						
(a) May 1...	May 10..	Nicotine sulphate (1–500), fish-oil soap 1 ounce to 1 gallon.	217	123	56.6	Greatest efficiency within 24 hours of treatment.
(b) May 1...	May 10..	Nicotine sulphate (1–800), fish-oil soap 1 ounce to 1 gallon.	152	86	56.5	Same as above.
(c) May 19..	May 23..	Nicotine sulphate (1–1,000), fish-oil soap 1 ounce to 1 gallon.	45	30	66.6	Lower leaves turned yellow and died on most plants.
(d) May 19..	May 23..	Volatile nicotine sulphate (1–1,000), fish-oil soap 1 ounce to 1 gallon.	72	35	48.6	Slight blackening of tips on larger leaves.
(e) May 1...	May 10..	Linseed-oil emulsion plus nicotine sulphate (1–800).	80	2	2.5	Not efficient.
(f) May 7....	May 9...	Fish-oil soap 1 ounce to 1 gallon.	Many.	0	0	All emerged successfully; not efficient.
(g) May 1...	May 10..	Check	Many.	0	0	All emerged successfully.
(h) May 19..	May 23..	Check	Many.	0	0	Same as above.

Discussion of results.—The data represented in Table VI are self-explanatory as to the relative value of the various strengths and combinations of insecticides. The mathematical representation of the first two lots does not clearly define the actual state of affairs. It was repeatedly observed that on the day following treatment the number of adults killed was usually larger than on the second or third day. In other words, the effectiveness of such practices depends entirely on the interval which elapses between applications, and the conclusion to be drawn is that nightly or daily applications are absolutely necessary to get the maximum killing. The insecticide proved to be effective in killing the adult in the act of emergence, but did not sufficiently penetrate the tissues of the leaves to kill the immature stages within the galls. The column "Total killed" is understood to mean the killing of the adult in the process of emergence (Pl. II, B). It is also important that the treatment should be applied when the adults are almost ready to emerge from the galls.

EXPERIMENT 3.

In the foregoing experiment it will be observed that good results were obtained with the nicotine sulphate diluted to 1–800. Another point upon which it seemed desirable to have more definite information was the effectiveness of applications made daily compared with those made two days apart. In the following experiment two lots were treated, while the third lot served as a check. The empty galls were punctured and all old pupal skins were removed from the plants in question. Eighteen plants were employed in each of the two treated lots, which were sprayed a total of five times. Five plants served as a check.

TABLE VII.—*Results on first and second days after treatment.*

Lot.	Treatment.	Results first day after treatment.				Results second day after treatment.			
		Males.	Females.	Total killed.	Pupal skins.	Males.	Females.	Total killed.	Pupal skins.
1	Nicotine sulpnate 40 per cent (1–800) and soap	38	43	81	15	1	1	2	16
2	Volatile nicotine sulphate 40 per cent (1–800) and soap	18	18	36	22	1	2	3	23
3	Checks	0	2	2	74				

Conclusions.—The results are very conclusive and show distinctly that the best results are obtained by daily application. There is a remarkable decrease in the numbers caught on the second day following treatment. Nicotine sulphate, therefore, used at the rate of 1–800 plus soap (1 ounce to 1 gallon) will control the adult on emergence, and hence is very well adapted to such cases where fumigation can not be followed consistently.

EXPERIMENTAL WORK IN COMMERCIAL CHRYSANTHEMUM GREENHOUSES.

Experimental work in a commercial greenhouse in Baltimore during the summer of 1918 seems to indicate that the chrysanthemum midge can be held well under control by spraying the infested plants with 40 per cent nicotine sulphate applied at the rate of 1 part of nicotine sulphate to 500 parts of water, with the addition of one-half ounce of soap to each gallon of solution. No appreciable injury followed the application, although the plants were sprayed every other day for a period of six weeks. The application of this treatment by the grower resulted in his producing especially fine chrysanthemums. It would appear that a double benefit was realized by such practices. In the first place it controlled the insect, and, secondly, a distinct stimulation of growth followed. This seems to confirm the work of Gossard (30) and Guyton (31), who claim that 40 per cent nicotine sulphate diluted with 500 parts of water and fish-oil soap will kill the adult almost immediately after emergence, if the spray is applied not more than three or four days previously.

A separate sash house was erected closely adjoining the greenhouse in which the spraying was done. Here 100 plants were fumigated nightly for approximately eight weeks, tobacco paper at the rate of 1 sheet to every 650 cubic feet of space being used. While some burning resulted, the midge was held in check. From these two experiments it is evident that either practice would be efficient.

A large commercial grower in Indiana reports that following instructions of this bureau he entirely eliminated the midge from his houses by fumigating with tobacco papers every night from December 20, 1917, to March 20, 1918.

Experiments conducted in several greenhouses in the District of Columbia in 1919 have indicated that consistent nightly fumigation is very effective in keeping down this insect. In several places where this was not advisable an effective spray was applied, consisting of nicotine sulphate (1–800) plus soap (one-half ounce to 1 ounce to each gallon of solution).

SUMMARY OF CONTROL AND RECOMMENDATIONS.

From the life history, as well as from the experimental data thus far submitted, it is clear that certain points must be kept in mind if the best practical results are to be secured. First, several generations are always present in greenhouses during the spring and fall occurrences; second, the adults emerge and mate during the very early morning hours, and egg laying quickly follows; third, preliminary control experiments show that the egg stage may be controlled by means of spraying or dipping the cuttings or plants; fourth, it has been demonstrated that the adult can be killed easily at the time of emergence by consistent spraying; fifth, fumigation experiments in a commercial house proved that the adult is easily killed by fumigation either with nicotine papers or hydrocyanic-acid gas; sixth, experiments applicable to general propagation practices show conclusively that such measures offer a reasonable safeguard and protection against doubtful stock and infested material without injury to the plants.

By adherence to a definite control program, involving any of the above cited measures, either singly or in combination, the insect can be readily controlled.

In case of a very light infestation daily picking of gall-infested leaves will hold the pest in check. Should this practice prove ineffective, nightly fumigation for a period of two or three weeks may be resorted to.

When a severe infestation is encountered the most heavily infested plants should be taken out immediately and burned.

This should then be followed by either fumigation or spraying as outlined below.

Fumigate every night, with either nicotine papers or hydrocyanic-acid gas, for a period of at least six weeks. This will kill all the adults that emerge during such a period and at the same time will prevent the further laying of eggs for future generations. The dosage need not be very heavy in either case. When nicotine papers are used one sheet to every 1,000 cubic feet of space will suffice. If hydrocyanic-acid gas [1] is employed, one-eighth to one-fourth ounce per 1,000 cubic feet will kill all of the adults. The use of hydrocyanic-acid gas is not recommended unless in the hands of a competent fumigator, owing to its deadly poisonous effects. Too much emphasis can not be laid on the fact that the fumigation must be set off after 12 o'clock, midnight, to be effective. It is preferable to start the generation between the hours of 12.30 a. m. and 2 a. m. Any fumigation done before midnight would be useless for it has been pointed out that the adult does not emerge until after midnight. On the other hand, if it is started later than 2 a. m. many adults will have emerged and laid their eggs.

In case fumigation is not advisable, especially where chrysanthemum plants are isolated or when other varieties of plants are present in the houses, spraying is recommended. This must be done consistently for a period of four to six weeks, a 40 per cent solution of nicotine sulphate extract diluted (1–800) being used, and soap added at the rate of one-half to 1 ounce per gallon of solution. The application should be made late in the afternoon in order that the best results may be obtained. In this manner practically all adults can be killed at the time of emergence and any eggs present will be destroyed.

PREVENTIVE MEASURES.

It has been proved that the means of disseminating this insect has been the shipment of infested chrysanthemums, both plants and cuttings. Interceptions made by the various State inspection officials, as well as by inspectors of the Federal Horticultural Board, definitely confirm this fact. It is therefore imperative that only clean plants and cuttings be brought into commercial houses where chrysanthemums are growing or to be grown. Growers should carefully examine all chrysanthemums received and see that all material intended for shipment or distribution is free from this pest. Any questionable material should at once be submitted to the State

[1] For further information on the use of hydrocyanic-acid as in fumigating greenhouses, see Farmers' Bulletin 880.

experiment station or to the Bureau of Entomology, United States Department of Agriculture.

The California Experiment Station (18) recommends the practice of growing the bulk of the chrysanthemum crop under cloth as a satisfactory means of preventing the attack of the gall-fly.

As a further preventive measure, it is recommended that cuttings be dipped in the following solution at the time they are taken:

Nicotine sulphate, 40 per cent	part	1
Water	parts	800
Laundry soap	ounce per gallon	½–1

Another satisfactory method of securing chrysanthemum cuttings free from the midge when the previous season's stock has been infested is to plant the stocks in benches or cold frames directly after the season's crop has been removed. This should then be followed by thorough treatment with a mixture consisting of equal parts of dry or air-slaked lime and tobacco dust. It is advisable to keep all new growth covered with the mixture until further operations in the spring.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 834

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER May 19, 1920

BLACK GRAIN-STEM SAWFLY OF EUROPE[1] IN THE UNITED STATES.

By A. B. GAHAN, *Entomological Assistant, Cereal and Forage Insect Investigations.*

CONTENTS.

INTRODUCTION.

That another exotic insect with possibilities for damage to agriculture has become established in America, that it is now quite widely distributed, and that it has already begun to make itself felt was brought to light during the summer of 1918. In view of its probable future importance and the consequent desirability of learning as soon as possible the facts about its distribution, food plants, and injuriousness, it is deemed expedient to bring the matter to the notice of entomologists and others through publication at this time of such information as is at hand.[2]

[1] *Trachelus tabidus* (Fab.).

[2] The writer is indebted to Miss Margaret Fagan, of the Bureau of Entomology, for compilation of the appended bibliography; to Messrs. W. R. McConnell, P. R. Myers, and W. J. Phillips, also of the Bureau of Entomology, for reared and collected material and notes which were invaluable in establishing the identity and distribution of the insect; to Dr. J. Chester Bradley, of Cornell University, for larval material of *Cephus pygmaeus* as well as useful suggestions regarding characters for separating the larvæ; and to Messrs. S. A. Rohwer and Wm. Middleton for numerous helpful suggestions.

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HISTORY OF DISCOVERY OF THE INSECT IN AMERICA

Specimens of a sawfly were collected by C. W. Johnson at Riverton, N. J., some time prior to 1899, the exact date unknown. These were submitted to Dr. W. H. Ashmead for determination and pronounced by him a new species, to which he gave the manuscript name of *Calameuta johnsoni.* Under this name, misspelled *Calamenta johnsoni*, the record was published, without description, in the second edition of Insects of New Jersey, by John B. Smith (39).[1] A description based on these specimens was later published by Ashmead (40). Subsequently the type specimens were examined by Dr. J. Chester Bradley, who recognized in them the European species *Trachelus tabidus* Fabricius, and under this corrected name the record of the original collection was again published in the third edition of Insects of New Jersey (45). At that time, and for some time thereafter, nothing was known of the food plants of the species in this country. Such European records as existed were in the Russian literature, and because of difficulty in translation were largely overlooked. Since *Trachelus tabidus* was not known to be causing any injury, no particular attention was paid to it.

During the summer of 1918 a complaint was received by the Bureau of Entomology from a correspondent at Gaithersburg, Md., regarding the work of some insect which had caused his ripening wheat to fall badly, and the writer was detailed by Mr. W. R. Walton, in charge of Cereal and Forage Crop Insect Investigations, to investigate the outbreak.

Specimens of the injured stalks were received from the correspondent, some of which proved to contain larvæ of what was readily determined as a species of Cephidae. The insect was at first thought to be either *Cephus pygmaeus* Linnaeus or *Cephus cinctus* Norton. The former species had been known in the vicinity of Ithaca, N. Y., many years before, but so far as the records indicated, had succeeded in spreading but little from the point of original infestation and had never been recorded as seriously injurious. *Cephus cinctus* was known only from the western United States and was not believed to occur east of the Mississippi River except for a few localities in Michigan.

When the Maryland infestation was brought to the attention of Mr. S. A. Rohwer, specialist on sawflies, of the United States Department of Agriculture, Bureau of Entomology, he at once suggested the possibility that the insect might be *Trachelus tabidus* Fabricius. Several adult specimens of this species in addition to those originally taken at Riverton, N. J., were in the United States National Museum. These, as shown by the labeling, were collected at two or three differ-

[1] Numbers in parenthesis refer to "Literature cited," p. 14.

ent points in Maryland and Pennsylvania. The fact that *Trachelus tabidus* was thus known to occur in the region of the infestation and that it was the only species of Cephidae known to occur there which would be likely to have the habit attributed to this one, at once established a strong probability that it was the species concerned. This suspicion was confirmed when Messrs. W. R. McConnell and P. R. Myers, who had been engaged for several years in investigating the insect enemies of wheat and other cereals for the Bureau of Entomology in Maryland and Pennsylvania, turned over to the writer all of the sawfly material which they had secured from that region. This material all proved to be *Trachelus tabidus* and included several specimens which had actually been reared from wheat stubble in breeding cages, as well as numerous specimens collected by sweeping wheat. The reared material left little doubt as to the identity of the depredator in question. Reference to the European literature, especially that by a number of the more recent Russian entomologists, regarding *Trachelus tabidus*, cleared up whatever lingering doubts might still have existed.

The manner in which this insect became established in America is unknown and probably will remain a mystery. Any surmise as to the probable manner of introduction would be valueless and since it could have no effect upon the fact that it probably has come to remain, is omitted.

COMMON NAME OF THE SPECIES.

In Russian literature this species is referred to as the black sawyer or black sawfly because of its nearly uniform black color. The writer has ventured to modify this name to some extent by calling it the black grain-stem sawfly. This name is descriptive of the insect as well as of its habit and at the same time minimizes the possibility of confusion with other black species of sawfly.

DISTRIBUTION.

OLD-WORLD DISTRIBUTION.

André (33) records the species as occurring in England, France, Sweden, Spain, Germany, Italy, Algeria, and Syria. Cameron (35) in his "Monograph of the British Phytophagous Hymenoptera" gives practically the same distribution, omitting France. Konow (42) in Genera Insectorum cites middle and southern Europe, Algeria, and Asia Minor. Several writers, including Shtchegolev (49), Kurdjumov (48), Uvarov (50, 54), Zolotarevsky (53), and Borodin (52), have recorded it more recently from central and southern Russia, while Kulagin (47) states that *Cephus pygmaeus* and *Trachelus tabidus* have been recorded from 26 different governments of Russia.

From this it will be seen that the species occurs in all three Old World continents, being present throughout most of the middle and southern European countries, southeastern Asia, and northern Africa. It is probable that it will eventually be found to be present throughout most of the remaining regions where wheat is grown in Europe and eastern Asia, as well as northern Africa.

DISTRIBUTION IN AMERICA.

The present distribution in America, gleaned from the writer's investigations, the records of Messrs. McConnell and Myers, which were kindly placed at his disposal, specimens in the United States National Museum, and a note furnished by Dr. J. Chester Bradley, includes localities in six States, viz: New Jersey, Virginia, Delaware, Maryland, Pennsylvania, and New York.

The localities where the insect is at present known to occur, together with the date of collection and the name of collector, are as follows:

Riverton, N. J., adults collected by C. W. Johnson, May 29 (year not given but prior to 1899); East Falls Church, Va., hibernating larvæ in wheat and rye stubble, A. B. Gahan and S. A. Rohwer, collectors, August 6, 1918; Warrenton, Va., larvæ collected in August, 1918, by W. J. Phillips; Harrington, Del., larvæ collected in wheat stubble by W. R. McConnell; Wolfsville, Md., adults swept in clover field by J. A. Hyslop, June 6, 1914; Hagerstown, Md., adults swept from wheat by P. R. Myers and W. R. McConnell, May 15, May 25, June 4, 1915, and May 24 and June 8, 1916; Hagerstown, Md., adults reared from wheat stubble by P. R. Myers, May 10, 1916, and by W. R. McConnell, May 3, 1917; Taylors Island, Md., adult reared from wheat stubble by W. R. McConnell, March 21, 1917; Great Falls, Md., adult swept by Frederick Knab, May 24, 1914; Germantown, Md., larvæ injuring wheat received from a correspondent by the Maryland State College of Agriculture, and recorded under the name of *Cephus pygmaeus* in Report of Maryland State Horticultural Society, 1914; Gaithersburg and Laytonsville, Md., hibernating larvæ collected by A. B. Gahan in wheat stubble, July 22, 1918; College Park, Md., hibernating larvæ in wheat by A. B. Gahan, July 24, 1918; Berwyn, Md., hibernating larvæ in rye stubble collected by A. B. Gahan, July 30, 1918; Laurel, Md., hibernating larvæ in wheat stubble, by A. B. Gahan, July 26, 1918; Towson, Md., hibernating larvæ in wheat stubble, by A. B. Gahan, August 2, 1918; Warfordsburg, Pa., adult reared from wheat stubble by P. R. Myers, June 5, 1916; Hunters Run, Pa., adult reared from wheat stubble, W. R. McConnell, May 7, 1918; West Chester, Pa., adult collected by H. L. Parker, June, 1915; Linglestown, Pa., adults collected by H. B. Kirk and A. B. Champlain, May 26, 1908; Herndon, Pa., adults, collector unknown, June 6, 1907; State College, Pa., adult swept in clover by W. R. McConnell, May 30, 1911; Carlisle, Pa., larvæ collected July 23, 1918, by C. C. Hill, and July 31, 1918, by W. R. McConnell; Mt. Holly Springs, Pa., larvæ collected in wheat stubble, June 25, 1918, by McConnell and Myers.

In addition to these records Dr. J. C. Bradley states that he has seen one adult specimen in the collection of the Brooklyn Museum from Long Island, N. Y.

These records probably indicate only approximately the present distribution (fig. 1) of the species. A more extended investigation will be necessary to establish the exact limits. The records are sufficient to establish a probability that it already occurs over the greater part of Virginia, Maryland, Pennsylvania, New Jersey, and Delaware, and it is possible that West Virginia, eastern Ohio, southern New York, and even some of the New England States may already be included within its range.

PROBABLE FUTURE DISTRIBUTION IN AMERICA.

Judging by its wide distribution in the Old World, as well as by the character of localities already included within its range in this country, including both tidewater and mountain districts, there seems little reason to doubt that the species will eventually spread over all the wheat-growing sections of the eastern and central United States. Whether it will accommodate itself to the arid and semiarid wheat-growing districts of the West is matter for speculation. The average precipitation of this region does not differ greatly from that of southern Russia, where the species seems to be at its worst. The mean temperatures of the two regions probably are not widely different. It seems possible, therefore, that unless some other climatic or physical factor intervenes, the species may spread eventually from coast to coast. That it will spread northward into Canada may be doubted, since in Europe, although recorded from Sweden, it seems not to occur generally in the colder northern portion.

FIG. 1.—Present known distribution of *Trachelus tabidus* in America.

FOOD PLANTS.

FOOD PLANTS IN EUROPE.

In European literature, with one exception, the records of food plants of *Trachelus tabidus* are by Russian entomologists. Rudow (43), in speaking of *Cephus satyrus* Panzer, *C. nigrinus* Thomson, *C. pallipes* Klug, *C. arundinis* Giraud, and *C. tabidus* Fabricius, makes the general statement that in southern Europe these species live in

Triticum repens, Bromus, Holcus, and reeds or bulrushes, without specifying which plants serve as host plants for the different species. The record is, therefore, too general to be of much value in the present circumstances.

The Russian records are more specific and apparently all refer to infestation of small-grain crops. Shtchegolev (49) records the species as a serious pest of wheat; Borodin (52) reared it together with *Cephus pygmaeus* from barley and both spring sown and winter sown wheat; Kulagin (47) states that it infests rye and wheat in the Province of Taurida. Various other Russian writers, including Uvarov (50) (54), Zolotarevsky (53), and Kurdjumov (48), have recorded the species as attacking the grain crops, principally wheat.

FOOD PLANTS IN AMERICA.

Thus far in America only wheat and rye are known to serve as food plants. Only two instances of its occurrence in rye are known, both observations having been made by the writer during the past summer. In each instance in which it was found in rye only one infested stalk was located in the field, although careful search was made. Although several fields of oats stubble were examined more or less carefully, no infestation of this crop was observed even when the oats were in close proximity to infested wheat fields. No opportunity to examine barley has offered itself.

It appears fairly certain that of the cultivated grain crops wheat will prove to be its preferred food plant. As stated elsewhere, the writer was able to find larvæ in varying quantities in every wheat field visited in the course of the limited investigation carried on during the summer of 1918.

That the species eventually will be found to infest plants other than the small grains is possible. The related species, *Cephus cinctus*, which also infests the small-grain crops in our Western States, is known to have a long list of food plants among the coarser grasses, both wild and cultivated. *Cephus cinctus* is believed, however, to be a native species whose original food plants were wild grasses and whose habit of attacking the cultivated grains has been induced through elimination or reduction of its natural source of food supply by the development of agriculture. Present information indicates that the natural food plants of *Trachelus tabidus* are the small grains, although it may yet prove to have other hosts in Europe. It is doubtful whether the species which has been transplanted from its native habitat to America will find it possible to develop in our native grasses. Only future investigation can determine. The possibility of its being able to maintain itself upon grasses other than the small grains should be borne in mind, and such grasses as Elymus, Bromus, Agropyron, and in fact any of the cultivated or wild grasses whose seasonal development is such as to provide a succulent stem of sufficient size to accommodate the larvæ during the period of larval activity, May and June, should be viewed with suspicion.

SYNONYMY AND DESCRIPTION OF TRACHELUS TABIDUS.

Since the original description by Fabricius (1), the name has undergone a number of generic transfers, and it has been redescribed or referred to under several specific names.

It is the opinion of the writer, however, that some of the published synonymy is incorrect. *Trachelus haemorroidalis* Jurine (17) is listed as a synonym by Dalla Torre (38). The figure given by Jurine is not that of *tabidus*, but is undoubtedly identical with *Cephus analis* Klug (12). The latter name is generally recognized by European writers as a synonym of *haemorrhoidalis* Fabricius (2). Konow (41) includes *Sirex macilentus* Fabricius (9), *Cephus erberi* Damianitsch (30), and *Cephus vittatus* Costa (32) as color varieties of *tabidus*. The large number of specimens of *tabidus* examined by the writer show no variation in color comparable to *macilentus* as illustrated by Coquebert (10), and since other European writers generally have recognized this as a distinct species it has been excluded from the synonymy. *Cephus erberi* is described as having the third to seventh dorsal abdominal segments banded with yellow, the band on the third segment interrupted, while the third to ninth ventral segments are said to be margined with yellow laterally. In no specimen of *tabidus* examined by the writer is there any indication of a dorsal band of yellow on the abdomen nor are the ventral segments margined with yellow. Like *macilentus*, this species is therefore excluded from the synonymy. The description of *vittatus*, on the other hand, agrees closely with *tabidus*, and there seems to be no good reason why it should not be considered a pure synonym instead of a color variety.

Following is the complete synonymy of *Trachelus tabidus* as understood by the writer:

Trachelus tabidus (Fabricius) Jurine.

Sirex tabidus Fabricius (1), (2), (4).—Villers (5).—Linné (6).—Christ (8).—Fabricius (9).—Coquebert (10).—Walckenaer (11).—Rossi (19).—Herrich-Schäffer (26).—Duméril (29).

Tenthredo longicollis Fourcroy (3).—Villers (5).

Astatus tabidus Klug (12).—Panzer (15).

Cephus tabidus Fabricius (13).—Latreille (14).—Panzer (16).—Latreille (18).—Lepeletier (20).—Stephens (23).—Hartig (24).—Blanchard (25).—Lucas (27).—Costa (28).—Taschenberg (31).—André (33).—Cameron (34), (35).—Magretti (36).—Costa (37).—Dalla Torre (38).

Trachelus tabidus Jurine (17).—Curtis (22).—Konow (41), (42).—Rudow (43).—Kokujev (44).—MacGillivray (45).—Kholodkovsky (46).—Kulagin (47).—Kurdjumov (48).—Shtchegolev (49).—Uvarov (50).—Borodin (52).—Zolotarevsky (53).—Uvarov and Glazunov (54).—MacGillivray (55).—Howard (56).

Cephus nigritus Lepeletier (20).

Cephus vittatus Costa (32).

Calamenta johnsoni Ashmead (39).

Calameuta johnsoni Ashmead (40).

Cephus pygmaeus Cory (51), not Linnaeus.

ADULT.

Female.—Long and slender, with abdomen somewhat compressed. Antennæ longer than thorax, thickened at apex, third joint slightly shorter than fourth, third to eighth joints four to five times as long as thick, those beyond eighth gradually shortening, the ones in thickened portion of antennæ subequal and not longer than broad; clypeus truncate at apex, with sharp lateral angles; occiput concave; greatest width of posterior orbit about equal to greatest transverse diameter of eye; pronotum elongate, nearly as long as broad, broadest at posterior margin, its sides more or less concave; mesoscutum and scutellum subequal in length; middle and hind tibiæ each with two apical spurs and normally each with two (sometimes one only) superapical spurs located at about the apical one-third of tibiæ; abdomen much longer than head and thorax, subcompressed, with sheaths broad and slightly thickened at apex. Polished black; mandibles except at apex, small spot below tegulæ, apex of front femora within, inner side of front tibiæ for its whole length, spot at apex of median femora in front, a broad longitudinal stripe along lateral margins of dorsal segments, a lateral spot on seventh ventral segment, and a narrow marginal stripe on basal part of sheaths yellow; wings subhyaline, nervures and stigma black. (See Pl. II, A.)

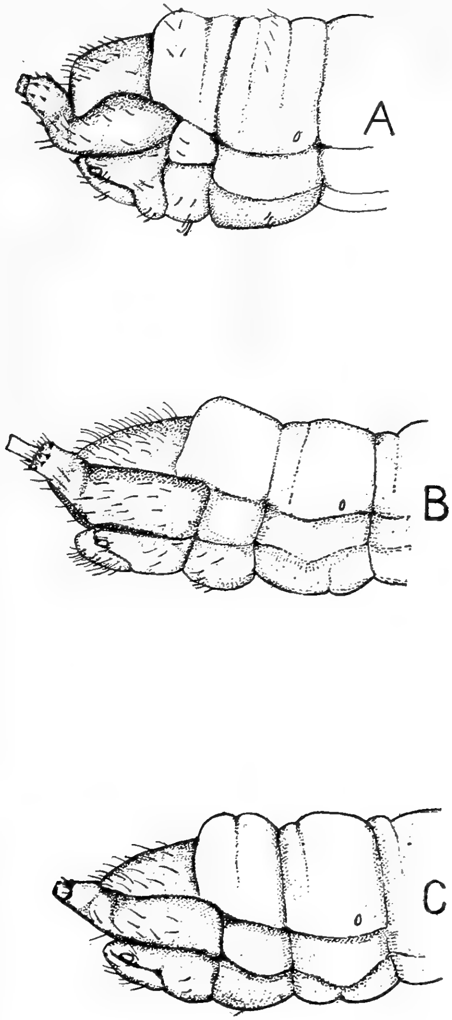
Male.—Similar to female in general appearance and color. Last visible ventral segment of abdomen prominent and extending beyond last dorsal segment; two ventral segments before last visible segment each with a broad, deep, horseshoe-shaped depression, within which is a transverse row of stiff, erect bristles. (See Pl. II, B.)

The only species occurring in America, so far as known, with which this species is likely to be confused are *Cephus cinctus* Norton and *Cephus pygmaeus* Linnaeus. The female may be readily distinguished by the fact that in both *cinctus* and *pygmaeus* the sheaths are narrower at apex than in the middle, and the dorsal segments are banded apically with yellow. The legs are also more largely yellowish. The male of *tabidus* differs from the males of the other two species in the presence of the horseshoe-shaped depression on the two ventral segments as well as by the color characters pointed out for the female.

OVERWINTERING LARVA.

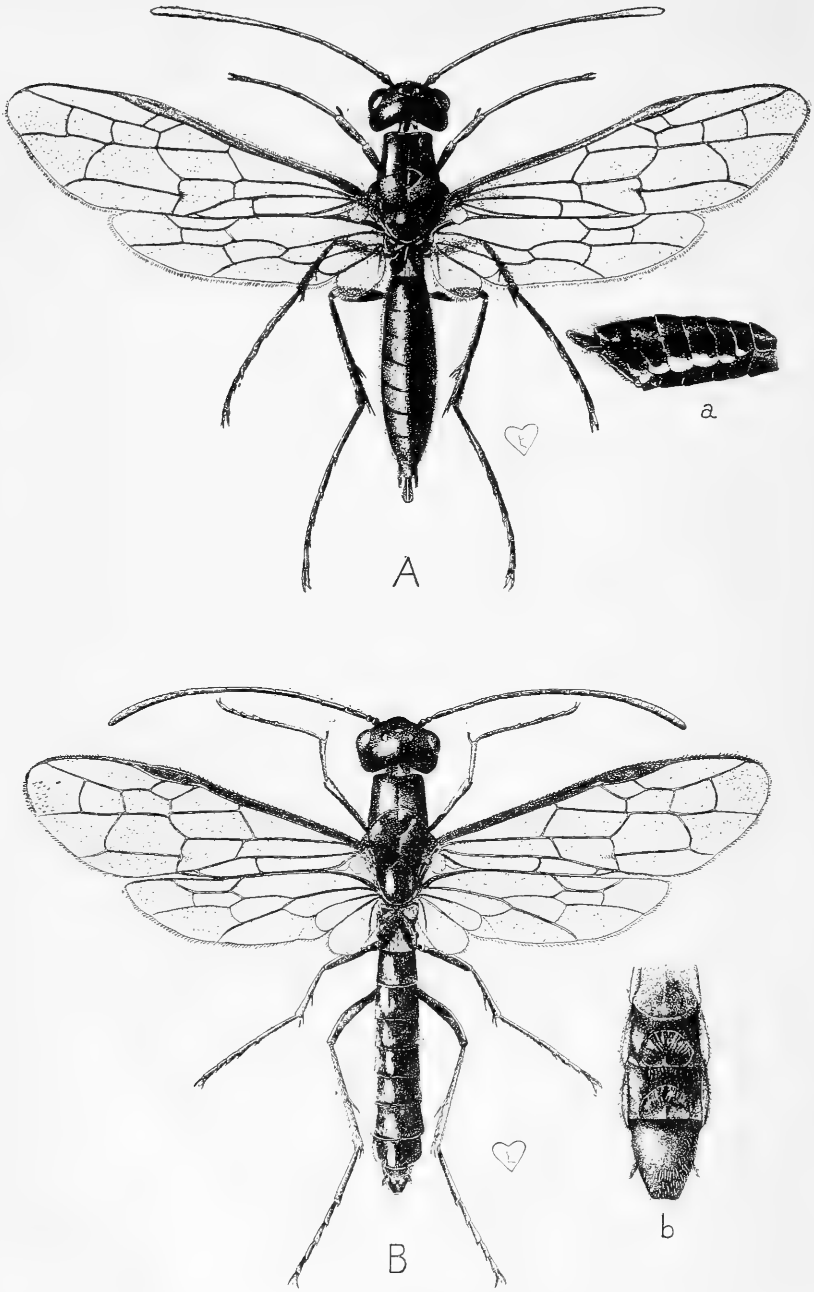
Body subcylindrical, yellowish white in color, 7 to 9 mm. in length, thoracic region slightly thicker than abdominal region. Living larvæ more or less tinged with greenish due to body contents.

Head pale yellow, its dorso-ventral length 1.1 mm., breadth 1.1 mm. Antennæ 5-jointed, tapering to a point at apex, more or less fuscous in color. Mandibles four-toothed, brownish, their apices nearly black; labrum, sutures about



THE BLACK GRAIN-STEM SAWFLY OF EUROPE IN THE UNITED STATES.

A, *Trachelus tabidus:* Lateral view of apical segments of larva; B, *Cephus cinctus:* Lateral view of apical segments of larva; C, *Cephus pygmaeus:* Lateral view of apical segments of larva.



TRACHELUS TABIDUS.

A, Adult female: *a*, Lateral view of female abdomen. B, Adult male: *b*, Ventral view of male abdomen.

clypeus, and articulations of mandibles brownish. Thoracic legs small, papilliform, and pale brownish. Dorsal abdominal segments triannulate; pleura prominent; ventral segments triannulate; prolegs absent. (For further description see Plate I, A, and key to larvæ.)

Larvæ of this species are apt to be confused with those of *Cephus pygmaeus* and *C. cinctus*. All three species infest the small grain crops in practically the same manner, have very similar biologies, and superficially resemble one another closely. The following key in conjunction with the accompanying figures will, it is believed, make it possible to recognize them:

KEY FOR SEPARATING GRAIN-INFESTING SAWFLY LARVÆ.

1. Dorsal anal lobe of the tenth tergite viewed from the side triangular, sloping gradually from base to apex, the anterior end of lobe much thicker than the posterior end which is more or less acute. Spines on the anal prong each arising from a small, more or less chitinized tubercule and closely grouped about the apex of the enlarged fleshy portion just basad of the short chitinized apical ring. Eighth and ninth tergites apparently glabrous-- 2.

   Dorsal and lobe viewed from the side not triangular, not sloping gradually from base to apex but convexly rounded, the posterior end of the lobe as thick dorso-ventrally as the anterior end and nearly perpendicular. Anal prong completely encircled by two irregular series of widely separated, short, stiff spines which do not arise from chitinized tubercules. Eighth and ninth tergites each with a transverse row of distinct short hairs. (See Plate I, A.)------------------------*Trachelus tabidus* Fab.

2. Anal prong terminating in a short chitinized ring which is not as long as broad. Spines basad of chitinized ring few in number, confined to a single transverse row on the dorsal surface. Dorsal, lateral, and ventral lobes all sparsely hairy. (See Pl. I, A.)---------------*Cephus pygmaeus* Linn.

   Anal prong terminating in a chitinized tube-like process which is distinctly longer than broad. Spines basad of the apical tube-like process numerous, arranged in two irregular contiguous series completely encircling base of tube. Anal lobes all more distinctly hairy. (See Pl. I, A.)-------------- --*Cephus cinctus* Nort.

MANNER OF WORK AND PROBABLE LIFE HISTORY.

Observations by the writer supplemented by those of McConnell and Myers, and confirmed in part by Kulagin (47) indicate that the life history of *Trachelus tabidus* does not differ greatly from that of the western grass-stem sawfly, *Cephus cinctus*. The early stages have not yet been observed in this country. Collections of adults in the field indicate that egg-laying takes place during the period May 15 to June 10. Some of the emergence records for reared specimens show somewhat earlier dates than May 15, but since these were obtained under the abnormal conditions of the laboratory they may be disregarded. Kulagin indicates about the same period for egg-laying in Russia.

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The eggs are inserted in a slit made by the female in the stem some distance above the ground. The young larvæ burrow downward through the pith of the stem, hollowing it out to the base. The larvæ apparently attain full growth at about the time the grain is ripe. At the time the writer's investigations were begun, July 22, they were full grown and had evidently gone into hibernation. The fully-developed larvæ were, at this time, located at the extreme base of the stem, encased in a silken tube or lining to the burrow, this tube being two or three times the length of the larva and filling the hollow straw completely from about the surface of the ground downward. Above this silken tube the burrow is completely closed by a wad of frass. Before this wad of frass is put in place the larva almost completely severs the stem from the inside, this cut in nearly every case being at or very near the surface of the ground and usually a little above the first node on the stem where the surface roots put out. In making this cut just enough of the epidermis of the straw is left unsevered to attach it lightly and allow it to stand erect. In consequence of this cut the first slight bending of the ripened straw, as by a strong wind, causes it to snap off and fall.

Straws cut off by the insect are easily distinguishable from those severed by the harvester. The cut is exactly transverse to the stem and the ends of both the stub which remains in the ground and the fallen straw are distinctly concave or funnel-shaped. This appearance is so characteristic that one can readily detect the presence of the pest in a field by simply examining the ends of the fallen straws.

The hibernating larva, as already stated, is to be found in the stub of the wheat stalk remaining in the ground. Since this stub in most cases barely extends to the surface of the soil (sometimes a little above the surface), it is not always an easy matter to locate it. The fallen straws sometimes remain slightly attached on one side to the stub, and in such instances one can locate the infested stub by following the straw to its base. When the straw is completely detached, as is usually the case in a field that has been harvested, it is often necessary to search for some time before the stub containing the larva can be located.

The greater part of the insect's life cycle is apparently spent as a hibernating larva, this period extending from about the time the wheat is ripe enough to cut until some time the following spring when the larva changes to the pupa. Just when this change takes place has not been ascertained, but the pupal state is probably of short duration, as in *Cephus cinctus;* if so, the change to the pupa probably occurs in the latter part of April or early part of May. Adults, as already stated, are to be found in the fields during the latter half of May and early June.

In the case of one male specimen reared from wheat stubble by McConnell, the insect was collected as a larva September 30, 1915, and emerged as an adult May 3, 1917. This shows that under some conditions the life cycle may be extended over a two-year period. Such instances are probably rare under natural conditions, but the record indicates a high degree of adaptability on the part of the species for overcoming unfavorable conditions.

EXTENT AND CHARACTER OF INJURY.

Shortly after receipt of the complaint from Gaithersburg, and before the identity of the insect was known, the writer was detailed to visit the locality and investigate the nature and extent of the damage. Accordingly, on July 22, 1918, the farm of the correspondent, Mr. Beverly R. Codwise, was visited. It lies about 3 miles north of Gaithersburg on the road to Laytonsville, Md. Unfortunately the infested fields had already been harvested, making it practically impossible to estimate the extent of the actual injury. It was evident, however, that there had been an appreciable loss due to falling of the grain, so that it could not be picked up by the binder. The writer was informed that comment by passers-by on the large amount of grain missed by the binder had first called attention to the injury and caused the investigation which resulted in the sending of samples to the Bureau of Entomology.

Three other farms in the neighborhood of Gaithersburg were visited, on each of which the pest was located. Subsequently wheat fields in various other localities in Maryland and one in Virginia were visited, with the result that in every wheat field examined the insect was found to be present in varying abundance.

No actual counts of infested straw were made by the writer in any of the fields to ascertain the percentage of infestation. It was roughly estimated that in some of the worst cases the infestation amounted to 4 or 5 per cent. In most of the fields the infestation was much less than 4 per cent. Messrs. McConnell and Myers did make counts of the infested stubble on a small number of experimental plats and other fields of wheat at Carlisle and Mount Holly Springs, Pa., with the results showing an infestation varying from 4.36 per cent on one of the plats to 0.26 per cent on another, the average from all counts being 1.75 per cent.

That a 4 per cent infestation of stubble necessarily indicates a 4 per cent loss in the crop is not probable. The insect apparently chooses only well-developed and vigorous stems in which to oviposit, and some of these infested stems are known to develop at least partially filled heads. Just what the loss, if any, from failure of the heads on infested stalks to fill properly may be, remains to be determined.

It is certain that serious loss may and does occur because of falling of the grain due to the cut made by the larva preparatory to hibernation. The extent of this loss will in all probability depend in some degree upon weather conditions during the period of ripening of the grain. A heavy wind or severe storm at this time would cause most of the infested grain stalks to break off and fall so that they would not be picked up by the harvester. In the absence of such a wind or storm, the loss would undoubtedly be much less, but even with favorable conditions a certain percentage of the infested stalks would be broken off by the harvester reel and fall in front of the platform.

Kulagin (47) states that losses in Russia due to this species and *Cephus pygmaeus* are estimated at 14 to 20 per cent, although more severe in some cases. Shtchegolev (49) also reports 15 to 20 per cent injury due to these two pests. Other Russian writers record severe injury without specifying the amount. Unfortunately, in practically every instance these writers treat of the injury by *Cephus pygmaeus* and *Trachelus tabidus* collectively, without indicating how much of the damage is chargeable to each. This is no doubt due to the fact that they have been unable to distinguish the larvæ of the two species. Their records, therefore, do not afford a reliable basis for estimating the probable future importance of *Trachelus tabidus* in this country.

PARASITES.

In Russia two parasites of *Trachelus tabidus* have been recorded. *Collyria calcitrator* (Gravenhorst), an ichneumonid wasp, is apparently a common parasite of this species as well as of *Cephus pygmaeus.* Borodin (52) records the chalcidid *Arthrolysis* (*Picrocystus*) *scabricula* Nees as having been reared from these two sawfly pests. Neither of these species has, as yet, been found in America.

The existence of at least one efficient parasite in America has, however, been established. Numerous specimens of a chalcidoid belonging to the genus Pleurotropis and apparently representing an undescribed species have been reared by Mr. W. R. McConnell at Mount Holly Springs and Carlisle, Pa. So far little is known of the life history of the species. It emerges from the prepupal larva of the Trachelus at about the time of emergence of the host adults and is believed to be a primary parasite, solitary in its habit. Observations to date are too limited in extent to form a very accurate estimate of the efficiency of this parasite, but in some instances at least it appears to exercise a considerable degree of control.

SUGGESTIONS FOR CONTROL.

In the present state of our knowledge of this species only suggestions of possible means of control can be given.

Measures for control will doubtless be similar to those against *Cephus cinctus*, the western grass-stem sawfly, and *Cephus pygmaeus*. It is obviously impracticable to attack the insect in the egg stage or active larva stage, since both stages occur in the growing grain. The adult can not be reached by any known method. It appears, therefore, that control measures to be successful must either aim at destruction of the hibernating larva or pupa while in the stubble, where the insect passes the greater part of its existence, or be confined to cultural methods such as crop rotation. The fact that the larva is located in the part of the stem below the surface of the ground precludes the possibility of accomplishing anything by any ordinary burning of the stubble. Disking the stubble thoroughly as soon after cutting the grain as practicable would possibly be of benefit by turning the infested stubble out and thus exposing the larva to the action of summer heat and winter cold. The larva is quite hardy, however, and only experimentation will prove or disprove the effectiveness of disking.

In Russia plowing down of the stubble as deeply as possible is recommended against this species as well as against *Cephus pygmaeus*. The same treatment is recommended and has proved successful against *Cephus cinctus* in this country, and it seems the logical treatment for adoption against this species. To be effective the plowing must bury the stub containing the larva so deeply that the maturing adult will be unable to escape. Shallow plowing will not suffice, as the adults undoubtedly will be able to burrow their way out if covered with only 2 or 3 inches of soil. Deep and clean plowing, therefore, will be essential. The plowing may be done at any time between the cutting of the grain and the following spring prior to emergence of the adults in April or May.

If, as now seems probable, this insect confines itself, in this country, to the small-grain crops as host plants, there can be little doubt that crop rotation will prove an effective means of reducing damage from it. Wheat, barley, or rye should be followed by some crop which will not serve as a host plant, such as corn or truck crops. The present practice on some farms of growing wheat on the same ground two years in succession is distinctly favorable to the propagation of the pest since the adults upon emerging find themselves surrounded by ideal conditions for oviposition. The practice also of sowing grass or clover with wheat and allowing the wheat stubble containing the larva to stand undisturbed for two seasons could hardly be improved upon as means of increasing the numbers of this insect. Any system of rotation to be effective should insure thorough plowing down of the wheat stubble and the growing of some crop other than a small grain following wheat.

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(31) TASCHENBERG, E. L.

1871. EINIGE NEUE SÜDEUROPÄISCHE HYMENOPTERA. *In* Zeitschr. f. d. Ges. Naturw., Bd. 4 (n. s.).

Page 306: Description of *Cephus tabidus*; found in Island Lesina.

(32) COSTA, A.

1878. RELAZIONE DI UN VIAGGIO PER L'EGITTO, LA PALESTINA, E LE COSTE DELLA TURCHIA ASIATICA PER RICERCHE ZOOLOGICHE. *In* Atti Acc. Sci. Napoli, v. 7, no. 2.

Page 14 (footnote): Species described as new under name of *Cephus vittatus;* from Egypt.

(33) ANDRÉ, ED.

1881. SPECIES DES HYMÉNOPTÈRES D'EUROPE ET D'ALGÉRIE . . . Beaune, Côte-d'Or, Tome 1.

Page 535, no. 31: Description of *Cephus tabidus;* found in England, France, Spain, Switzerland, Algeria, Italy, Germany, Syria.

(34) CAMERON, P.

1886. A SYNOPSIS OF THE BRITISH SPECIES OF CEPHINA. *In* Ent. Mo. Mag., v. 22, p. 175–177.

Page 177: Brief description of *Cephus tabidus;* synonymy; table.

(35) ———

1890. A MONOGRAPH OF THE BRITISH PHYTOPHAGOUS HYMENOPTERA. London. v. 3.

Page 120, no. 6, Pl. 3, fig. 9: Description, previous references in literature, and synonymy of *Cephus tabidus.* Found in England, Sweden, Germany, Spain, Italy, N. Africa, Syria.

(36) MAGRETTI, P.

1890. IMENOTTERI DI SIRIA . . . *In* Ann. Mus. Civ. Stor. Nat. Genova, (2) v. 9, p. 522–548.

Page 528: *Cephus tabidus* recorded from Europe, Algeria, Syria.

(37) COSTA, A.

1894. PROSPETTO SISTEMATICO DEGLI IMENOTTERI ITALIANI. Napoli. Pars 3.

Page 253: *Cephus tabidus* recorded from Italy and Sicily.

(38) DALLA TORRE, C. G. DE.

1894. CATALOGUS HYMENOPTERORUM . . . Lipsiae. v. 1.

Page 412: Bibliographic catalogue of *Cephus tabidus.*

(39) [ASHMEAD, W. H.] *In* SMITH, J. B.

1900. INSECTS OF NEW JERSEY. *In* Ann. Rept. Sta. Bd. Agr., Suppl., 1899. p. 501–615.

Page 600: Species listed as *Calamenta* [*Calameuta*] *johnsoni.*

(40) ASHMEAD, W. H.

1903. TWO NEW PHYTOPHAGOUS HYMENOPTERA. *In* Can. Ent., v. 35, p. 233.

Page 600: Species described as new under name of *Calmeuta johnsoni,* from Riverton, New Jersey.

(41) KONOW, FR. W.

1904. SYTEMATISCHE ZUSAMMENSTELLUNG . . . Chalastogastra. *In* Zeitschr. Hym. Dipt., v. 4, p. 225–288.

Page 256: Description and synonymy of *Trachelus tabidus*. Found in South and Middle Europe, North Africa, and Asia Minor.

(42) ———

1905. HYMENOPTERA: FAMILY LYDIDAE. *In* Wystman, P., Genera Insectorum, Fasc. 27.

Page 20: Synonymy of *Trachelus tabidus*. Found in South and Middle Europe, North Africa, and Asia Minor.

(43) RUDOW, F.

1909. LEBENSWEISE DER HOLZWESPEN, SIRICIDAE. *In* Intern. Ent. Zeitschr., Jahrg. 3, p. 123–124.

Page 124: Record of *Trachelus tabidus* from South Europe. Also records of host plants which are doubtful.

(44) KOKUJEV, NIKITA.

1910. SUR LA DISTRIBUTION DES REPRÉSENTANTS DE LA SOUS-FAMILLE DES CEPHINI KONOW . . . EN RUSSIE ET LA DESCRIPTION DES ESPÈCES NOUVELLES. *In* Rev. Russ. Ent., v. 10, p. 127–139.

Page 137: *Trachelus tabidus*.

(45) [MACGILLIVRAY, A. D.] *In* SMITH, J. B.

1910. REPORT OF THE INSECTS OF NEW JERSEY. *In* Ann. Rept. N. J. Sta. Mus., 1909.

Page 595: Synonymizes *Calamenta* [*Calameuta*] *johnsoni* and repeats record of occurrence in Riverton, New Jersey.

(46) KHOLODKOVSKY, N.

1912. A COURSE IN ENTOMOLOGY THEORETICAL AND PRACTICAL. Petrograd. v. 2.

Page 472: *Trachelus tabidus*.

(47) KULAGIN, N. M.

1913. THE PRINCIPAL INSECT PESTS OF FIELD CROPS IN EUROPEAN RUSSIA FOR THE LAST TWENTY YEARS. *In* Yearbook Dept. Agr. Centr. Bd. Land Admin. and Agr. Petrograd. v. 6, p. 585–638. (Rev. Appl. Ent., ser. A, v. 2, 1914, p. 201–202.)

Records *Trachelus tabidus* from 26 governments; more frequent and injurious in southern governments. Damage about 14 to 20 per cent, sometimes more.

(48) KURDJUMOV, N. V.

1913. THE MORE IMPORTANT INSECTS INJURIOUS TO GRAIN CROPS IN MIDDLE AND SOUTH RUSSIA. *In* Studies from Poltava Agr. Exp. Sta., no. 17, Dept. Agr. Ent., no. 6, 119 pp. (Rev. Appl. Ent., ser. A, v. 2, 1914, p. 170–173.)

Trachelus tabidus from South Russia on rye.

(49) SHTCHEGOLEV, I. M.

1913. REPORT ON INJURIOUS INSECTS AND DISEASES OF PLANTS IN THE GOVERNMENT OF TAURIDA DURING THE YEAR 1912. In Rept. Ass't. Ent. of Govt. of Taurida, Simferopol, p. 24–56. (Rev. Appl. Ent., ser. A, v. 1, 1913, p. 357.)

Records *Cephus tabidus* as having attacked 15 to 20 per cent of the wheat crop.

(50) UVAROV, B. P.

1914. REPORT OF THE ENTOMOLOGICAL BUREAU OF STAVROPOL FOR 1913. *In* Dept. Agr. Centr. Bd. Land Admin. and Agr. Petrograd. 86 p. (Rev. Appl. Ent., ser. A, v. 3, p. 44–47.)

Records *Trachelus tabidus* injuring wheat; not determined if more injurious than *Cephus pygmaeus* as differences in larvæ are still unknown.

(51) COREY, E. N.

1914. INSECT PESTS OF 1914. *In* Rept. Md. Sta. Hort. Soc., v. 17, p. 104–112.

Page 106: Records *Cephus pygmaeus* injuring wheat at Germantown, Md. (Undoubtedly a misidentification of *Trachelus tabidus*.)

(52) BORODIN, D.

1915. CEPHUS PYGMAEUS L., ON THE WESTERN EXPERIMENTAL FIELD OF THE AGRICULTURAL EXPERIMENT STATION OF STAVROPOL, CAUCASUS. *In* Husbandry, Kiev, p. 876–883. (Rev. Appl. Ent., ser. A, v. 4, 1916, p. 21.)

Records *Trachelus tabidus* infesting stubbles of barley, and winter and spring sown wheat in Stavropol.

(53) ZOLOTAREVSKY, B. N.

1915. PRELIMINARY REPORT ON THE WORK ON ENTOMOLOGY IN 1914. *In* Stavropol-Caucasian Agr. Exp. Sta., Stavropol. 12 p. (Rev. Appl. Ent., ser. A, v. 3, 1915, p. 479–480.)

Records *Trachelus tabidus* as appearing later than *Cephus pygmaeus*, and chiefly found on summer-sown crops.

(54) UVAROV, B. P., & GLAZUNOV, V. A.

1916. REPORT ON THE WORK OF THE ENTOMOLOGICAL BUREAU OF STAVROPOL FOR 1914. *In* Dept. Agr., Ministry of Agr., Petrograd, p. 13–54. (Rev. Appl. Ent., ser. A, v. 4, 1916, p. 460.)

Records large outbreak of *Trachelus tabidus* in 1914, with large numbers of parasites.

(55) MACGILLIVRAY, A. D.

1917. HYMENOPTERA OF CONNECTICUT. Part 3. Tenthredinoidea. *In* Bull. 22, Sta. Geol. & Nat. Hist. Survey, Conn.

Page 174: Description of *Trachelus tabidus*.

(56) HOWARD, L. O.

1918. REPORT OF THE ENTOMOLOGIST. *In* U. S. Dept. Agr. Annual Repts. 24 p.

Page 7: Record of *Trachelus tabidus* injuring winter wheat in Northern Virginia, and throughout Maryland and Pennsylvania.

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THOMAS H. MacDONALD, Chief

Washington, D. C. PROFESSIONAL PAPER August 6, 1920

CAPILLARY MOVEMENT OF SOIL MOISTURE.

By WALTER W. MCLAUGHLIN, *Senior Irrigation Engineer.*

CONTENTS.

The irrigation engineer has long felt the need of more detailed information as to the importance of capillarity as a source of loss of water from irrigation works and the part it plays in distributing, within the soil, water applied in irrigation. It has long been recognized that impounding reservoirs and conveying channels lose more water than can be accounted for by direct percolation and evaporation. Whether this loss was the result of capillary action alone or in combination with the transpiration from plant growth along canal banks has been only a matter of conjecture. Where the water applied to soil by irrigation goes and how it ultimately distributes itself within the soil have been questions of speculation.

It has been observed that the percentage of moisture determined in the field in the usual way has not always given a true basis upon which to determine the necessity of applying water by irrigation. In some instances, the percentages of moisture determined have been above the wilting point and yet plants were wilted.

This condition has caused the irrigation engineer to speculate upon the probability of the rate of movement of soil moisture from one point to another by capillarity, as well as the extent to which the moisture may move.

The irrigator is always confronted by questions of methods of irrigation, duration of irrigation, and frequency of irrigation. The

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first aim is to obtain a uniform distribution of moisture within reach of the plant roots and to maintain such distribution. The economical application of water to prevent waste from deep percolation or surface run-off and to maintain an optimum percentage of moisture within the soil is the vital problem. For instance, under specified soil and topographic conditions, how long should the furrows be and how far apart? With turns of irrigation coming at specified intervals, how much water should be applied and how long should an irrigation be continued at each turn? To approximate an accurate answer to questions of this kind it is necessary to know more accurately than we now know the rate and extent of movement of the soil moisture by capillarity during the several periods of an irrigation season.

The drainage engineer in the arid region has frequently been perplexed by a condition of water-logging under conditions which seem to preclude the possibility of the movement of free water as such from any known source to the wet area. He has often felt a want of specific information which would indicate the development of free water from capillary moisture and the importance of this form of moisture in farm drainage.

OBJECT.

As a basis for answering some of the above questions investigations were undertaken in 1915, and the data given below are in the form of a progress report.

The object of these experiments is to furnish specific data as to the capillary movement of moisture in the soils of the arid region. It is felt that these will be of prime importance to the irrigation engineer in the proper construction and operation of conveying channels and impounding reservoirs, and that they will enable him to point out the most economical methods of applying water to fields. These data were obtained for different soils and under different conditions.

PLAN OF EXPERIMENTS.

Because it was realized that the rate and extent of movement of moisture in soils by capillarity differs materially where the source of moisture is a body of free water from where it is a body of wet soil, the experiments have been divided into two parts:

1. Where the source of the moisture is a body of free water into which the soil column extends.

2. Where the source of moisture is a body of soil containing a percentage of moisture greater than the wilting percentage, and not connected with a body of free water.

The work as planned and carried out embodied a study of the rate and extent of capillary movement of moisture in columns of various types of soil, where capillarity was assisted by gravity, where it acted against gravity, and where gravity as a factor was eliminated.

The columns in which gravity was to assist capillarity were inclined downward at various angles from the horizontal; the columns in which gravity was to act against the force of capillarity were inclined upward at various angles from the horizontal; and the columns in which the effect of gravity was to be eliminated as far as possible were set horizontal.

Inasmuch as evaporation is one of the factors that controls the extent and rate of movement of soil moisture by capillarity, it was decided to run each set of experiments in duplicate, except that one column was to be covered on all sides and evaporation reduced to a minimum, while the other column was to be uncovered and exposed on one side to the air.

It was essential to the plan of the experiments that the probability of free water as such entering the columns be reduced to a minimum and yet have sufficient water enter the flumes to give something with which to work. It was desired to have a high initial percentage of capillary water, and at the same time eliminate free water. To accomplish this end it was decided to have a vertical lift from the surface of the water in the tank to the bottom of the container of the soil column proper of from 3 to 4 inches. After several preliminary tests a vertical lift of 4 inches was adopted and all columns except the vertical ones (unless otherwise stated) have a vertical "lift" of 4 inches from the surface of the water in the tanks to any change in direction of the column. That part of the soil column from the surface of the water to the point of change in direction has been termed the "wick" in the discussion which follows.

Air-tight joints were maintained and no water escaped from the tanks except by the wick and no moisture from the columns except by evaporation. To guard against the formation of a true siphon within the soil column an air space was maintained upon at least one side of the soil column throughout its entire length, in the columns inclined downward.

All water added to the tanks after the initial filling was measured and recorded. At specified intervals the position of the outward extent of the wet area of soil was measured and these measurements recorded.

The experiments in which a moist soil was the source of moisture rather than a body of free water differ but little from those described, except that evaporation was eliminated in all cases.

The soil boxes were partially filled with a soil containing a known percentage of moisture, greater than the wilting percentage, and the remainder of the box filled with air-dry soil packed firmly against the wet soil. The boxes were set either vertical or horizontal, no inclined boxes being used. In the boxes set vertical, in some experiments, the wet soil was placed at the top of the box and the air-dry soil was placed at the lower end. In other boxes the wet soil was placed at the lower end of the box and the air-dry soil at the upper end. Thus, the movement of the moisture from the wet soil into the dry soil by capillarity would be, in some cases, with the force of gravity and, in other cases, in an opposite direction. A few vertical boxes had the middle section of the box filled with the wet soil, with the air-dry soil at both ends, thus combining in the same box and at the same time the upward and downward movements.

The horizontal boxes were packed in the same way as the vertical boxes with wet soil at one end and air-dry soil at the other. In a few tests the middle section of the horizontal boxes was filled with wet soil and air-dry soil placed at both ends. In a very few tests the middle part of the box was filled with two sections of wet soil containing different initial precentages of moisture and the dry soil was placed at both ends of the box.

METEOROLOGICAL DATA.

In connection with the experiments a record was kept of the evaporation from a free water surface and a thermograph record taken of the air temperature. No other meteorological data were recorded.

SOILS USED.

A uniform surface soil was selected for each set of experiments. This soil was to be typical of a large area and was to be of a well-known type. The soils were to be obtained from various parts of the arid region that the data might be of general value. The greater the number of types and the wider the range in types of soils used, the greater the value of the tests. Uniform soils were to be used, as the movement of moisture by capillarity varies in soils of different types and the results obtained with mixed soils would be of little value.

INCIDENTAL EXPERIMENTS.

The movement of soil moisture by capillarity within a soil of a uniform type differs materially from its movement between soils of different types. This difference is found in the rate and extent of movement and in the initial percentage of moisture necessary to permit movement. To obtain some light upon this point a few experiments were conducted. The general plan of these auxiliary experiments was about the same as for the original experiments. In the auxiliary experiments, various types of soil were packed in layers or one end of a column or box contained soil of one type and the other end soil of a different type.

METHOD AND EQUIPMENT.

A confined soil column was used and the method differed from that usually employed by other investigators only in the size and arrangement of soil columns. The columns used in these experiments are 100 square inches in cross-sectional area and much larger than the columns usually employed. A feature made important in the present work is the use of inclined columns.

One side and the bottom of each flume were made of wood with metal lining and the other side was of plate glass. In the discussion of the experiments the term "flume" will be used to designate the soil column and its container.

Uniform soil was packed into the flumes and wicks extended from within the water in the tanks up into the flumes. After the soil had been placed in the flumes the tanks were filled up to the initial level and this level rather constantly maintained throughout the experiment.

At 9 a. m. of each day and frequently at other hours the outward extent of the soil wetted by capillary moisture was measured, and the water in the tanks was brought up to the initial elevation with measured quantities of water added directly to the tanks. Soil samples were taken at various points in the wet soil area, at such intervals of time as deemed advisable and always at the end of an experiment. All the flumes or columns were protected by canvas from the direct rays of the sun and from the rain.

MEASURING THE ADVANCE OF THE CAPILLARY MOISTURE.

The outward extent of the wetted soil area, indicating the extent of the moisture movement at any time, is plainly visible through the glass side of the flume. The wetted soil is of a darker color and the line of demarcation is very distinct. The position of this line as seen through the glass side was traced upon the glass. The position of these markings with reference to the surface of the water in the tank is determined by five direct measurements made in the way and to the points as follows:

Five lines are drawn along the glass side of the flume parallel to the longitudinal axis of the flume. The first line is at the top of the glass; the second line is 2½ inches lower; the third is 5 inches from the top and at the middle of the glass side; the fourth is 7½ inches from the top, while the fifth is at the bottom of the flume and 10 inches from the top line. The intersections of the marks on the side of the flume indicating the outward extent of the wet soil area and the five lines above described give five definite points with which to locate each of the markings upon the glass side of the flume. The positions of these five points are determined by direct measurements from the surface of the water in the tank along the five lines parallel to the longitudinal axis of the soil column.

The original horizontal surface of the water in the tanks was used as a base for all measurements of the position of the moisture in the soil column in all flumes rather than a transverse line coincident with the change in inclination of the soil column, if any, from the vertical. Inasmuch as the movement of moisture in the soil columns by capillarity from free water is about equal for all inclinations, from the vertical upward to the vertical downward, for the first foot or more, using the surface of the water as a base for measurements does not produce an appreciable error in making comparisons.

In the experiments with wet and dry soils the initial point of measurement is the line of contact between the original areas of wet and dry soil. No water is added to the boxes after they are set up, but the water is added to the wet soil at the time of packing. The quantity of water to be added to the soil to be packed wet is calculated upon the dry weight of the soil and then this water is added by measurement.

MAINTAINING THE WATER LEVEL IN TANKS.

All water added to the tanks after the initial filling is added in measured quantities and recorded as water used by the flume. Water is added sufficiently often to maintain the level of water in the tanks at a rather constant elevation. The water added during any 24 hours is recorded as the water used during the day ending at 9 a. m. Unless otherwise specified all references to water used per day will mean for the day ending at 9 a. m.

SAMPLING FOR MOISTURE.

The soil is sampled for moisture with a ¾-inch carpenter's auger in the usual way and the samples immediately placed in tared screw-topped glass bottles and weighed. A composite sample is made of the upper 5 inches of soil and another composite sample for the lower 5 inches in each boring. The samples are taken in planes parallel to the planes indicating the advance of the moisture within the flumes at the points sampled. A boring is located by a measurement along the top of the flume from the water level. The samples, as soon as convenient after the first weighing, are placed in a water-jacketed oven and dried at the temperature of boiling water until a constant weight is obtained. Using the dry weight of the soil sample as a basis, the percentage of moisture in the sample is calculated.

The samples from the box experiments are taken and treated in the same way as for the flumes, except that one composite sample is made for each boring in the boxes.

PREPARATION OF SOIL FOR PACKING.

The soil to be used in the experiments is thoroughly air dried, if not already so. The soil is spread out in thin layers and exposed to the direct rays of the sun for several days. The air-dried soil is then screened through a ½-inch screen and all large rocks, roots, etc., removed. Lumps of soil are broken up and screened. The heavy clay soils having numerous large lumps are rolled with a hand lawn roller and screened. In order that the soil grains may not be broken by the roller, it is necessary to roll upon some rather yielding foundation. A soil foundation was made by rolling repeatedly with a weighted roller. Soils of the clay and loam type are passed through a 14-mesh screen and the screenings from all operations thoroughly mixed. The preparation of the heavier soils of the Whittier type is a slow and tedious operation. It is only by repeated rolling with a light roller that the soils can be properly fined without crushing the soil grains.

SETTING UP THE FLUMES.

The flumes were set up out in the open and were protected only from the direct rays of the sun and from the rain. They rest upon 2 by 12 inch plank cut to the proper length and set upon end. The tanks rest upon small stands fastened firmly to the foundation for the flumes. Thus the supporting structure for the entire soil column is rigid.

The flume, tank, and ell were set in position, the glass side of the flume put in position, and then all joints were filled with melted paraffin wax. All joints were tested a second time to see that they were air and water tight. The flume including the wick was then ready for packing.

PACKING SOIL IN FLUMES.

The soil was placed in the flume in 2-inch layers and packed with a wooden block and hammer. The block is corrugated and is 4 by 6 inches. The packing was done by striking the block with the hammer, using as uniform a blow as practicable and continuing the packing until the soil was of about the same density as found in the field. This density was estimated in both instances by measurement and weight. The soil was placed and packed into the flumes layer by layer until filled.

PACKING THE BOXES.

The boxes were packed with soil in much the same way as the flumes, except when the initial percentage of moisture in the wet-soil part of the box was relatively low. In this case, the soil was first wetted to the desired degree, and then placed in the box in layers one inch thick and packed by dropping a weight a given distance upon a board covering the layer of soil. The distance the weight was to be dropped, and the number of times it was to be dropped for each layer was determined by tests for each soil. The section of the box to be filled with air-dry soil was packed by using the hammer and block.

PREVENTING EVAPORATION IN FLUMES.

Those flumes in which evaporation from the top of the flume was to be prevented were covered with two-ply unsanded maltoid roofing paper. A strip of the roofing cut to the proper size was placed upon the top of the flume and reached from one end to the other. The side joints were made air tight. On the glass side of the flume the roofing was folded over and down on the outside of the glass about one-half inch. The joint between the roofing and the glass was held in place and made tight by means of an angle-iron strip made of galvanized iron clamped along the upper edge of the glass and on top of the roofing. To prevent air-trapping, ¼-inch vent holes were cut in the roofing at intervals of about 4 feet. Tests of the effectiveness of this covering to prevent evaporation of moisture from the flumes indicate that at least 80 per cent of the evaporation from an open flume was prevented by this covering.

A more effective method of preventing evaporation could be devised, but there would be great danger of the entrance of some unknown factors into the work. The entrance of these factors would prove fatal for comparison with much of the other work.

COVERING THE BOXES.

The plate-glass sides of the boxes were sealed to the boxes by means of cushions made of maltoid roofing. The glass was held in place and clamped tightly to the box by means of wooden strips fastened to the box proper by means of eyebolts fitted with thread and nut. Rubber cushions were tried, but did not give the same satisfaction that was obtained from the use of maltoid.

CAPILLARY ACTION IN THE SOIL IN THE ABSENCE OF FREE WATER.

The term "free water" as here used is water not held by capillarity and obeying the laws of gravity. It is variously termed "free water," "ground water," and "water of gravitation." (17.)[1]

[1] The figures in parentheses apply to the references at the end of this bulletin.

The plan of this experiment was to study the rate and extent of movement of moisture from a wetted soil into an air-dry soil when the two were brought in contact. The wetted soil was to contain various percentages of moisture from near the point of capillary saturation down to the wilting point.

THE SOIL BOXES.

The soil boxes or soil tubes for this work as first designed consisted of galvanized iron boxes 6 by 6 inches in cross section and of various lengths from 4 to 8 feet.

It was soon found that the metal boxes first used were not sufficiently rigid. They were difficult to pack and the least jarring of the box after it was packed and set in position was very apt to crack the soil column. The second set of equipment, the boxes now in use, is described later.

ADDING THE WATER.

Various methods were tried for adding the water to soil to be wetted and at the same time insure a uniform pack offering no mechanical obstacle in the movement of the moisture by capillarity. The method finally adopted as giving the most uniform results for the higher percentages of moisture was found not adapted to the smaller percentages of moisture. In the first method, the water was added to the soil after it had been packed and its distribution in that part of the soil column left to capillary action. In the second method, or the one used for the smaller percentages of moisture, the water was added before packing. Where the water was to be added after the soil was packed, a small furrow about 2 inches deep was made the entire length of the part of the column to be wetted and the proper amount of soil would take it up, and finally, with the last of the water was added that part of the soil removed to make the furrow. The wetted soil was then covered with plate glass and allowed to stand 24 hours before packing the air-dried part of the column. As soon as the dry soil was added the plate glass side was placed and sealed in position and the box set in place and the experiment was under way.

When the moisture was added before packing, a mass of soil sufficient for one pack was moistened to the desired percentage by adding a weighted quantity of water. The mass was thoroughly mixed by turning over and over several times on a piece of oil cloth. This soil was then placed in the box in layers 2 inches in thickness and tamped with a hard rubber tamping bar. The amount of tamping was much a matter of judgment and testing, except that the same soil with the same percentage of water used in different boxes received the same amount of tamping.

MEASURING THE ADVANCE OF MOISTURE.

The change in color of the soil in the dry part of the column with a change in moisture content was very marked in nearly all soils except the light sands, devoid of much organic matter. With the position of the contact of the wet and dry part of the column at the commencement of the experiment marked upon the glass side of the box, it was a simple matter to measure the distance the moisture had moved into the dry part of the column at any time. These measurements were recorded, as well as the date and hour of the measurement.

OTHER OBSERVATIONS OF THE SOIL COLUMN.

During an experiment and at its expiration close observations were made of the condition of the column for cracks or other factors that might influence the ultimate results. At the end of the experiment observations were made at the outer extremity of the apparent wetted area in the original dry part of the box to determine if the advance of the moisture had been the same in all parts of the column. In many cases it was found that the extent of the movement was a little greater upon one side of the column than upon the other. These differences were probably caused by differences in temperature rather than lack of uniformity in packing.

PROTECTION FROM SUN AND RAIN.

To protect the flumes from the direct rays of the sun and from the rain, canvas covers were provided. These covers were held away from the sides of the flumes and from the top by iron bows and iron strips similar to the old-fashioned wagon cover. This provided ready circulation of air and ample protection from the weather. Inasmuch as each flume was protected in this way no corrections had to be made for the exposure of the flumes to the sun's rays due to differences in angles of inclination or their setting in reference to the compass. Figure 1 shows the tank ell or wick and a section of flume as they appear when in position for filling.

THE TANKS.

The tanks used to contain the water from which the soil columns obtain moisture are made of galvanized iron. They are 12 by 20 inches in area and 8 inches deep. Near the bottom and at one end of each tank is fitted a $\frac{3}{8}$-inch water-gage glass, extending upward upon the outside of the tank, so that the height of the water in the tank can be determined after the lid is placed in position. Around the outside and at the top of the tank is soldered a galvanized iron channel, three-eighths inch wide and three-quarters inch in depth. This channel is to receive the edge of the cover to the tank.

The lid of the tank is of material similar to the tank and has the outer edge turned down three-quarters of an inch all the way around to fit into the channel on the tank. Passing through the lid and

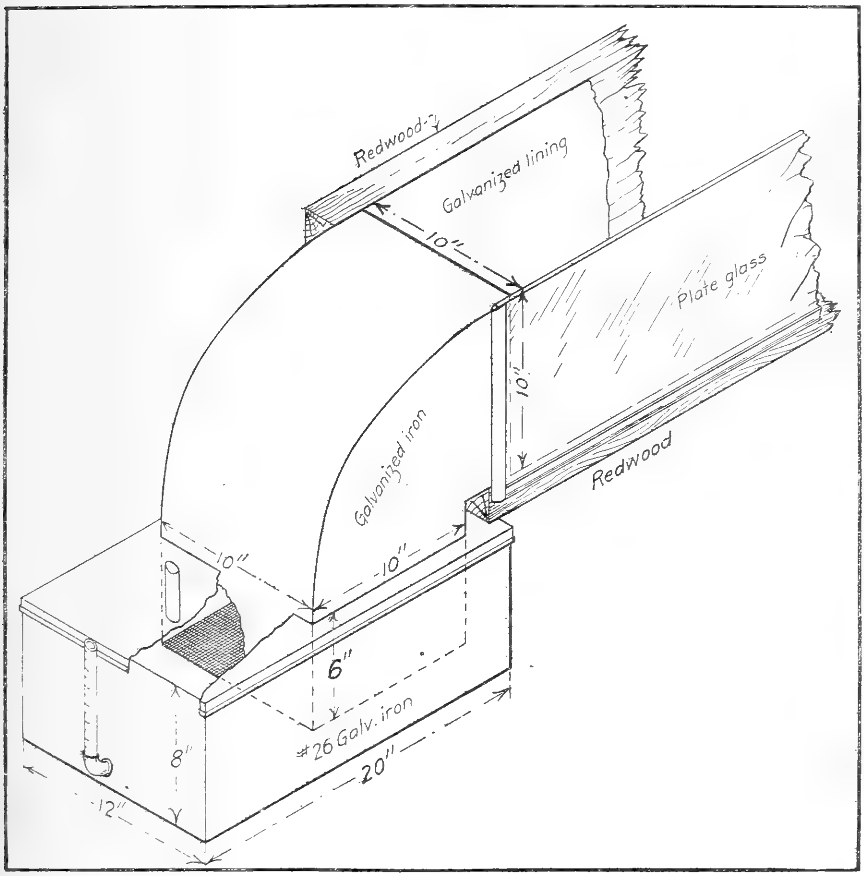

FIG. 1.—Isometric view of open flume connected by wick to supply tank.

soldered to it is the ell. Into the lid is fitted a $\frac{3}{4}$-inch tube through which water may be added to the tank. To support the weight of the ell and to stiffen the lid, two galvanized-iron channels are riveted to the underside of the lid, running crosswise of the tank. These channels are placed just outside the ell.

THE ELL.

The ell is, as the name implies, an elbow used to change the direction of the soil column from the vertical. It extends 6 inches within the tank and a few inches within the flume proper. The ell is made of galvanized iron and has a cross-sectional area of 100 square inches. The bottom end of the ell is closed with a piece of very fine meshed brass-wire gauze soldered to the ell. The angle of the ell is made sufficient to change the direction of the soil column from the vertical upward to any specified angle. The angles used varied from 45° up to 45° down.

THE FLUME.

The flume proper is that part of the equipment designed to hold that part of the soil column extending beyond the outer end of the ell. The bottom and one side of each flume are made of 2-inch redwood plank lined with galvanized iron. The second side of the flume is of plate glass, while the top of the flume is open or covered with maltoid roofing. The flumes are 10 by 10 inches in area and of various lengths. The galvanized lining of the flume at intervals of 1 foot is ridged or corrugated with ¼-inch channels extending up and into the flume. The metal lining on the bottom of the flume is bent down and over the edge of the plank bottom and then bent out and up on the glass side, forming a channel to receive the edge of the glass side. This channel is one-half inch wide and three-quarters inch deep.

THE GLASS SIDE.

One side of the flume is of stock plate glass cut 11 inches wide and 30 inches long. The glass is held in place at the bottom by the channel made by extending the lining of the bottom as described above. The ends of the glass are held in place by double channels made from galvanized iron. These channels are one-half inch in width, three-quarters inch deep, and 10½ inches long. The channels are fastened to the bottom of the flumes by means of screws and are held at the top by strap-iron cross-braces fastened to the wooden side. Melted paraffin is run into the channels at the bottom and end of the glass and a tight joint secured. The end of the flume is closed with a metal gate fastened to the wood of the flume.

SOIL BOXES.

The all-metal boxes as first used were replaced with wooden boxes having a metal lining. The sizes of the boxes were not altered. They are made of 2-inch redwood plank and lined with galvanized iron. The lining extends out and over on the open side of the box. A strip of plate glass held in place by wooden strips is placed on the open side of the box when ready to set in place after packing. The wooden strips are fastened to the box proper by means of eyebolts having a screw thread and nut for tightening. The joint between the glass and the box is made with a strip of maltoid roofing. The present box gives good satisfaction and is sufficiently rigid to admit of considerable handling without danger of cracking the soil column.

SOIL SAMPLING EQUIPMENT.

The soil samples are taken with a carpenter's bit, the shank of which has been lengthened to 16 inches. The soil samples are placed in 4-ounce glass bottles fitted with aluminum screw caps. They are dried in the usual double-walled water-jacketed oven. The oven used is of local make and of galvanized iron. The inner oven is 12 by 12 inches, fitted with one shelf.

EVAPORATION TANK.

The evaporation tank is made of galvanized iron, and is 18 inches square and 12 inches deep. The tank is set in a wooden box 2 inches larger all around than the tank. This space is filled with soil, thus insulating the tank upon the bottom and sides.

AIR TEMPERATURES.

The air temperatures are taken with a self-recording thermograph. The instrument is set up immediately adjacent to the flumes and is shaded and protected from storm.

ADDITIONAL EQUIPMENT.

A variety of special equipment has been used, and this will be described with the presentation of the data obtained by its use.

RATE AND EXTENT OF MOVEMENT OF SOIL MOISTURE BY CAPILLARITY.

There are so many factors controlling the rate and extent of movement of capillary moisture (4) (11) that it is very difficult to apply the data obtained from one soil to a different soil even of the same type. Without knowing more of the effects of those different factors upon the movement of soil moisture it is not possible to make such comparison and expect accurate quantitative results, even though we have a complete chemical and mechanical analysis of the two soils (8) (15). Within each soil are those influencing factors, such as soluble mineral salts, the organic material, the colloids, and many others, which influence in various and irregular ways the movement of soil moisture by capillarity. Certain other factors, such as the meteorological conditions that may be controlled to a large extent, exert a material influence upon the movement of soil moisture by capillarity.

In so far as the writer knows, there is very little knowledge of the quantitative effect of these different factors upon the movement of soil moisture, general information being limited to the fact that they do influence the movement. There are a few data upon the quantitative effect of temperature (2) and some of the other meteorological factors and also of the soluble salts (3), but they are incomplete and in some instances confusing. In the experiments herein discussed, the evaporation factor has been controlled and taken into account within certain limits, and the results of this work will be discussed later in the report.

In any comparison of the data from one soil with the data obtained from a different soil none of these factors has been taken into account. Chemical and mechanical analyses of the soil can be obtained readily, but with our present knowledge such information would be of no service in making quantitative comparisons. For instance: The colloids influence the movement of capillary moisture in one way, while the organic material, as indicated by the organic carbon, exerts an influence in the opposite direction. There is not sufficient information to indicate in the least to what extent these two factors might compensate, if at all. Other factors tend to retard the movement of the moisture, while others, again, tend to augment it, but to what extent our present information does not indicate.

The experiments herein recorded were run at various times throughout the year and in the open. Some of the soils were tested during the heat of August and others during the cold weather in January. Others of the soils were tested at a time when they encountered periods of almost extreme heat and extreme cold. It is known with reasonable certainty that the rate and extent of movement of soil moisture is greater with temperature above but near the freezing point than at a higher temperature. That a temperature of from 26° to 32° F. has a marked influence upon soil moisture other than the mere fact of freezing will be indicated by data presented later in this report.

In the data herein presented, no corrections are attempted for temperature or other factors unless specifically stated. It must be kept in mind that in the calculations for comparison and in the derivation of formulæ the conclusions reached are applicable only to the soil under consideration and under the same conditions.

MOVEMENT OF MOISTURE IN VERTICAL TUBES FROM FREE WATERS.

The experiments herein recorded differ from other work that has been done in vertical tubes only in that the tubes are larger and the work has been carried to a greater extent (3), (12), (13), (14). These tubes or flumes have also been subjected to variations of temperature corresponding to the daily and monthly variations in temperature of the atmosphere at Riverside.

A feature of the experiments not usually included is a record of the quantity of water required to extend the moisture to various heights.

Below is given a list of the vertical flumes and the soil placed in each.

Flume 19 was filled with decomposed granite from Riverside, Calif.

Flume 43 was filled with heavy soil from Riverside, Calif.

Flume 63 was filled with heavy clay soil from Whittier, Calif.

Flume 80 was filled with gravel soil from Uplands, Calif.

Flume 100 was filled with lava-ash soil from Central Idaho.

Flume 209 was filled with sandy soil from Central Idaho.

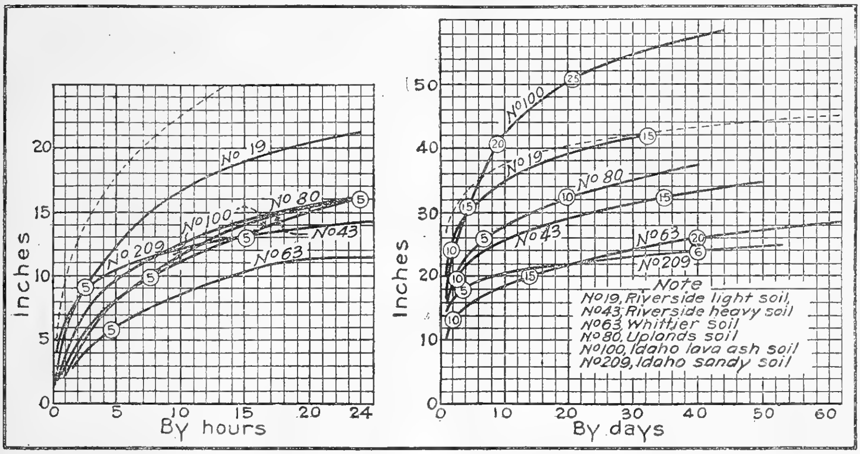

FIG. 2.—Rate of movement of moisture in vertical columns of soil. The numbers within circles indicate the point at which that number of liters of water had been taken up.

The moisture equivalent, in per cent, for these soils is as follows: Riverside, light, 7.9; Riverside, heavy, 14.1; Whittier, 38.3; Uplands, 6.6; Idaho lava-ash, 18.3; and Idaho sand, 4.7.

Figure 2 shows the curves derived from the measurements of the rate of movement of moisture in the flumes and the time of such measurements. The vertical element is the distance measured in inches and the horizontal element is the time in hours or days. The figure to the left shows the rate of movement by hours for the first 24 hours and the figures to the right the movement by days.

The curves are parabolos or closely resemble parabolic curves. A very rapid movement of the moisture occurs for the first few hours of the experiment. After the first few hours there is a rather rapid slowing down of the rate of movement and after about the fifth day the rate of movement is rather uniform, growing slightly slower day by day.

The diagram indicates that the rate of movement in the lighter soils is more rapid for the first few hours and then slows down much quicker than with the heavy soils. The heavier soils maintain a relatively more uniform variation than the lighter soils throughout the experiment.

The heavy Idaho soil is an excellent example of those soils having a high capillary power. It shows a steady extended movement and differs widely from the light Idaho soils, as shown by flume 209.

We find in these soils a variation of nearly 250 per cent in the total distance moved in a period of 30 days. In general, the lighter the soil, the shorter the distance the moisture will move upward in a long period of time.

The unnumbered dotted lines upon both the drawings in figure 2 represent the movement of moisture in vertical tubes of small diameter as found by Loughridge (13). These curves are introduced to show the agreement in results from experiments with small tubes and those from the experiments with flumes at Riverside. The soil used in these small tubes, as indicated by the dotted lines, is an alluvial soil from Gila River Valley.

Table 1 gives, in percentages, that part of the distance moved in 1, 2, 3, 5, 10, and 20 days of the total distance moved in 30 days.

Table 2 gives the same information in hour periods for the first 24 hours.

TABLE 1.—*Daily movement of moisture (distance) in percentage of movement in 30 days.*

Number of days.	Flume.					
	19	43	63	80	100	209
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	51	41	47	46	30	62
2	61	60	57	57	43	71
3	67	66	62	62	51	76
5	74	73	65	70	59	83
10	84	82	76	80	77	89
20	94	93	89	92	92	94
30	100	100	100	100	100	100

TABLE 2.—*Hourly movement of moisture (distance) in percentage of movement in 24 hours.*

Number of hours.	Flume.					
	19	43	63	80	100	209
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	27	15	....	....	14	44
2	39	25	29	38	29	58
3	52	45	....	56	....	69
4	63	57	47	66	55	80
8	72	70	....	71	63	81
12	84	80	83	83	74	90
24	100	100	100	100	100	100

The distance moved in 2 hours, in percentage of the total distance moved in 30 days, or 720 hours, was as follows:

Flume 19, 20 per cent; flume 43, 13 per cent; flume 63, 13 per cent; flume 80, 13 per cent; flume 100, 9 per cent; flume 209, 36 per cent. In 2 hours, or 1/360 of the time, the percentage ranges from 36 in the light Idaho soil to 9 in the heavy Idaho soil, or from about one-tenth to about one-third the total distance.

About the same relative rate of movement of moisture for the first few hours of the experiment is shown by Table 2. In the first 8 hours, or one-third of the 24 hours, the moisture had moved upward more than 70 per cent of the total distance moved in 24 hours, while in the longer period of 30 days it is found that more than 80 per cent of the total distance was covered in one-third of the time.

The above tables and diagram but emphasize and give in some detail the rapid action of capillary moisture when soils are first placed in contact with free water, and show that a large part of the total distance the moisture will move in a month is covered within the first few hours. These results are in accord with those obtained by others. (9)

WATER USED.

The figures within the small circles in figure 2 give, in liters, the total quantity of water removed from the tanks by the soil columns at the end of various periods of time.

At the end of 30 days, flume 63 had taken about 30 per cent more water than had flume 19, and flume 100 had taken up nearly twice as much water as flume 19. Flume 209 used very little water after the first 6 days and a large part of the total water used in the 30 days was used the first day. At the end of 30 days this flume had used only about one-half as much water as flume 19. These figures show, as was to be expected, that the lighter soils require less water per inch than do the heavier soils.

TABLE 3.—*Quantity of water used to move moisture an average distance of 1 inch at the end of different periods of time.*

Number of days.	Flume.					
	19	43	63	80	100	209
	Liters.	*Liters.*	*Liters.*	*Liters.*	*Liters.*	*Liters.*
1	0.422	0.446	0.700	0.250	0.482	0.296
2	.393	.526	.737	.256	.468	.276
3	.392	.506	.726	.323	.506	.265
4	.379	.500	.772	.311	.527	.259
10	.366	.470	.789	.326	.497	.254
20	.364	.484	.840	.317	.488	....
30	.357	.472	.816	.327	.484	.239

Except for the lighter soils of the sandy type, the quantity of water required to move the moisture the first inch is about the same or a little less than to move it the last inch on a basis of 30-day tests. Table 3 brings out the fact that there is much less difference in the quantity of water required per inch for the various heights than is usually supposed. The difference in the percentage of moisture found near the bottom and the percentage found near the top of a vertical soil column containing capillary water raised from a free water surface leads to the natural conclusion that more water per inch is removed for the bottom inches than for the top inches. However, it is observed that in flume 63 the reverse is true, although the percentage of moisture near the bottom of this flume was greater than it was within 4 inches of the top. Under another heading in this report is given at least a partial explanation of this apparent inconsistency. (See p. 56.)

TABLE 4.—*Water removed from tank, by days, in percentage of total removed in 30 days.*

Number of days.	Flume.					
	19	43	63	80	100	200
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	61	47	40	34	30	77
2	67	66	50	43	42	82
3	74	69	55	60	53	84
4	75	72	60	62	60	86
10	86	79	74	77	79	....
15	91	86	87	82	89	....
20	95	91	93	87	92	....
30	100	100	100	100	100	100

Table 4 shows in general the relatively high percentages of water removed from the tanks during the first day or two and the relatively small percentages used after the first three or four days. It is found that in all flumes at the end of the third day, or one-tenth of the 30 days, more than 50 per cent of the water had been used, and by the end of the tenth day three-fourths of the total water used in 30 days had been removed from the tanks. During the last 10 days of the experiment only about 10 per cent of the total water was removed from the tanks.

This table again indicates the longer continued use of the relatively large quantities of water by the heavier soils and the very rapid action of the lighter soils. This is of economic importance in that the loss for an extended time would be much less in proportion for a heavy soil than for a light soil where the loss of water is caused by capillary action alone.

In Table 5 are brought together for comparison the rate of advance of moisture and the quantity of water used, expressed in percentages of the totals for 30 days. (See Tables 1 and 4.)

TABLE 5.—*Percentage of distance moved and percentage of water used by days upon a 30-day basis.*

Number of days.	Flume.											
	19		43		63		80		100		209	
	Distance moved.	Water used.	Distance moved.	Water used.	Distance moved.	Water used.	Distance moved.	Water used.	Distance moved.	Water used.	Distance moved.	Water used.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	51	61	41	47	47	40	46	34	30	30	62	77
2	61	67	60	66	57	50	57	43	43	42	71	82
3	67	74	66	69	62	55	62	60	51	53	76	84
10	84	86	82	79	76	74	80	77	77	79	89	......
15	....	91	....	86	....	87	....	82	....	89	....	......
20	94	95	93	91	89	93	92	87	92	92	94	......
30	100	100	100	100	100	100	100	100	100	100	100	100

It is observed that in three of the flumes the percentage of the water used at the end of the first day exceeds the percentage of the distance moved; in two of the flumes this condition is reversed and in the other flume the two percentages are identical.

Table 6 shows the percentage of water (by volume) contained in the wet soil at the end of 30 days, and as would be expected, the relatively large quantity of water contained in the heavier soils.

Table 7 gives the depth in inches to which the water removed from the tanks at the end of the specified time would cover the surface of the soil column if none of the water so added penetrated the soil. For instance, at the end of the third day 671 cubic inches of water had been removed from tank 19. This quantity of water is sufficient to cover a 10-inch by 10-inch area to a depth of 6.71 inches. In the same way the other figures of the table have been determined. If the area of the flume had been 1 acre instead of 100 square inches there would have been removed from the tank sufficient water to have covered the acre to a depth of 6.71 inches, or, expressed in irrigation terms, there would have been removed from the tank 6.71 acre-inches in the three days.

TABLE 6.—*Percentage of water, by volume, contained in the wet soil.*

Flume.	Percentage of water.
19	21.82
43	28.80
63	30.02
80	20.55
100	29.60
209	14.60

TABLE 7.—*Depth to which water removed from tanks would cover area of 100 square inches.*

Number of days.	Flume.					
	19	43	63	80	100	209
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	5.49	4.27	4.88	2.44	4.88	2.59
2	6.10	6.10	6.10	3.05	6.71	2.74
3	6.71	6.45	6.71	4.27	8.54	2.82
4	6.86	6.71	7.32	4.47	9.72	2.89
10	7.78	7.42	9.00	5.49	12.81	....
15	8.24	8.08	10.62	5.86	14.34	....
20	8.62	8.54	11.35	6.24	14.95	....
30	9.06	9.36	12.21	7.17	16.17	3.36
40	9.31	9.70	12.57	7.48	17.39	....
50	....	10.00	13.06	....	18.37	3.86
60	....	....	13.42	....	....	....

Table 7 shows that if a body of water were covered with 40 inches of dry soil of the type in flume 100, there would be removed from it by capillarity in the first 10 days a depth of 12.81 inches of water.

If some means were provided to remove from the end of the wetted soil column in flume 100 after the end of the first day all the water the soil column of this length could transmit, there would be lost from this body of water at least 1.83 acre-inches each day, and in one year the loss would amount to 55.66 acre-feet per acre. This, then, is the transmitting power of the soil column at the end of the first day. That this amount is not lost each day following the first is due to the fact that the soil can not take this amount by capillarity through the distance from the free water. If a calculation were made for this soil to transmit water from the twentieth to the thirtieth day and at the distance from the water to the outer extremity of the moisture at this time, the transmitting power could be 3.17 acre-feet per acre per year or only 6.67 per cent of the transmitting power at the end of the first day. If the same calculation is made for flume 19, it is found that the transmitting power of this soil for the period from the twentieth to the thirtieth day is only about one-third that of flume 100, and about the same relative percentage at the end of the first day.

In flume 19 it is found that the moisture has traveled upward into the flume a total distance of 28.05 inches in three days and that there has been removed from the tank at the end of three days a total of 1,100 cubic centimeters or sufficient to fill the flume to a depth of 6.71 inches. Using these figures, it is found that at the end of the third day there was by volume 23.9 per cent of water in the 28.05 inches of wetted soil. By the same means of calculation Table 8 is computed.

Table 8 indicates that for a period of 30 days the light sandy soils contained a smaller percentage of moisture in the wetted area day by day. The heavier soils, as represented by flumes 43, 63, and

100, maintain a rather uniform percentage of moisture throughout the 30 days. (The distribution of this moisture throughout the column will be given later.) At the end of 62 days flume 63 contained in the wet soil by volume 47 per cent of water, or a little less than at the end of 30 days. At the end of 44 days flume 100 contained by volume 29.8 per cent of water, or about the same percentage contained for the first 30 days.

TABLE 8.—*Percentage, by volume, of water in wetted soil at end of time specified.*

Number of days.	Flume.					
	19	43	63	80	100	209
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	25.7	27.2	42.6	15.3	30.0	18.0
2	24.0	32.2	45.0	15.6	28.6	16.9
3	23.9	31.0	44.3	19.9	30.6	16.1
4	23.1	30.5	....	19.3	32.0	15.8
10	22.3	28.0	48.2	19.9	30.3	....
20	22.0	29.4	51.7	19.4	29.0	....
30	21.8	28.8	50.0	20.6	29.6	14.5

Table 8 would indicate further that capillary action must take place much slower in heavy soils than in light soils, due to the relatively higher percentage of moisture in the heavy soils at all points in the column. It takes a higher relative percentage of moisture in the heavy soils to permit the advance of moisture from a damp to a dry soil by capillary action. The lighter soils will contain a relatively smaller percentage of moisture in the very extremity of the wetted area as it advances than will the heavier soils.

DISTRIBUTION OF SOIL MOISTURE IN VERTICAL SOIL COLUMNS.

The distribution of moisture in a vertical column of soil, the lower end of which is in contact with a body of water (9), has received considerable attention in these experiments. The study has included the distribution for the various lengths of time up to and including 40 days. In Table 9 is given the distribution in two vertical columns for periods of 30 days, or after the column has been in contact with the water for a period of 30 days. Flume 43 is Riverside soil No. 1, and flume 63 is the Whittier soil. Flume 63 was closed to evaporation, while flume 43 was open upon one side, and the soil is held in place by brass-wire gauze.

TABLE 9.—*Distribution of moisture in vertical soil columns.*

Distance above water level (inches).	Riverside soil No. 1: Flume 43.	Whittier soil: Flume 63.
	Per cent.	*Per cent.*
1	17.40	43.74
3	17.40	45.53
6	20.44	40.25
9	18.84	40.70
12	12.67	40.84
15	....	38.11
18	12.65	35.49
21	....	34.75
24	12.44	30.82
28	....	24.59
30	10.15	....
31	....	5.59
36	6.35	4.00

The figures show that the decrease in the percentage of moisture from the water surface to the upper extremity of the wetted area is not uniform. In flume 43, the greatest percentage of moisture is found at a height of 6 inches above the water. In flume 63 there is a greater percentage of moisture in the twelfth inch than in either the sixth or the ninth inches. In both flumes there is a decrease in the percentage of moisture with height above the twelfth inch. In flume 43 there is a much more constant and uniform percentage of moisture from the twelfth inch to near the top of the wet area than there is in flume 63. In both flumes, the moisture content breaks very abruptly near the upper end of the wet soil and indicates the relatively high percentage of moisture necessary to allow the moisture to move from the wet to the dry soil.

Other and very much more numerous data show the irregularity of moisture distribution in vertical columns even though every precaution is taken to have the soil uniform in texture and in density. A superficial study of these data would indicate that a formula that would give the distribution of moisture in vertical soil columns for a period of 30 days would be more complicated than the formula for the movement of moisture. An analysis of the above statement would indicate that the percentage of moisture which will permit the advance of moisture from the wet to the dry soil is variable, even for uniform temperatures, etc.

The data for flumes 43 and 63 given above, and numerous other data show a distribution of moisture contrary to general supposition.

That there is a lack of uniformity in the distribution of moisture in vertical soil columns has been observed by others (6), (13).

THE MOVEMENT OF MOISTURE IN HORIZONTAL FLUMES.

The horizontal capillary movement of moisture within the soil and from a body of free water has not been studied before to any great extent (12).

Much of what has been said of the vertical flumes is applicable to the horizontal flumes. The chief difference is rather one of degree.

At the present time there will be discussed only the horizontal flumes open on top to evaporation.

The number of flumes and the soil contained in each is given in Table 10.

TABLE 10.—*Soil in horizontal flumes.*

Number of flume.	Description.
20	Decomposed granite soil from Riverside, Calif.
31	Heavy decomposed granite soil from Riverside, Calif.
50	Heavy clay loam from Whittier, Calif.
70	Sand and gravel wash from Uplands, Calif.
90	Heavy lava ash from Idaho.
200	Light sand soil from Idaho.

Figure 3 shows the curves derived from the measurement of the movement of moisture in the horizontal flumes and the time of such measurements. The vertical element is the distance measured from the surface of the water in the tank and the horizontal element is the time in days.

The resulting curves for all these soils have the parabolic form. Very rapid movement of the moistures occurs for the first few days, after which the rate of movement is more uniform, but it gradually decreases with the lapse of time. It is observed from the figure that the rate of movement of moisture in the heavier soils, as typified by the Whittier soil, subsides much more rapidly than does the movement in the sandier soils.

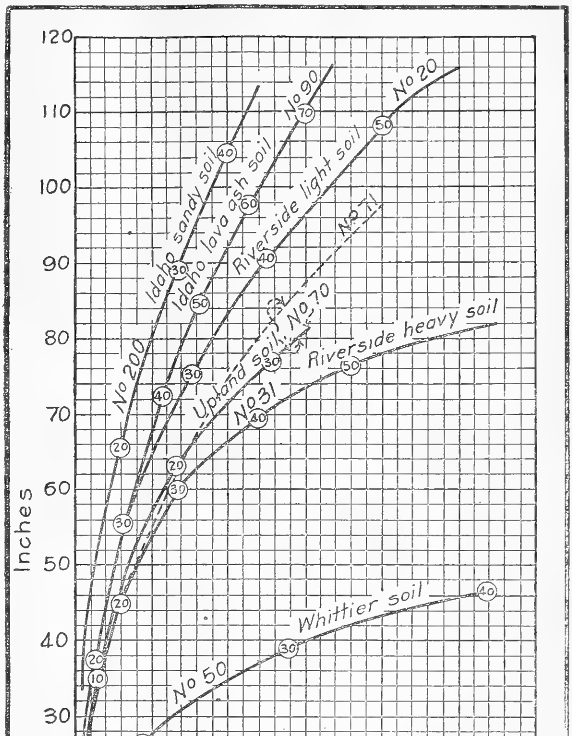

FIG. 3.—Rate of movement of moisture in horizontal open flumes. Figures in circles indicate points at which that number of liters of water had been taken up. The dotted line for flume No. 71 (covered) is for comparison with flume No. 70 (open).

The extent of movement of moisture in these soils is, with the exception of Idaho lava soil, in inverse order to their moisture equivalents. That is, the Idaho soil (sandy) with the lowest moisture equivalent showed the greatest movement of moisture, while the Whittier soil with the greatest moisture equivalent showed the least movement of moisture. The Idaho lava soil in the horizontal flume as in the vertical flume showed a greater movement of moisture than the moisture equivalent would indicate.

The figures within the small circles give in liters the quantity of water removed from the tanks by the soil columns at the ends of various periods of time.

Table 11 gives the percentages of water used in 1, 3, 5, 10, 15, and 20 days of the total quantity used in 30 days.

TABLE 11.—*Water removed from tanks by days expressed in percentages of amount removed in 30 days.*

Number of days.	Flume.				
	20	31	50	70	90
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	17	22	26	18	17
3	30	36	42	30	29
5	38	42	51	36	37
10	53	58	67	52	53
15	67	70	78	64	67
20	81	81	86	79	81
30	100	100	100	100	100

Table 11 shows the relatively great use of water the first few days of the experiment. In all cases more than one-half the total quantity of water used in 30 days was used the first 10 days or one-third of the time. From 17 to 26 per cent of the total quantity used in 30 days was used the first day and in two-thirds of the 30 days more than 80 per cent of the water was used. The lighter the soil the smaller the relative percentage of water used the first few days, and the heavier the soil the greater the relative use of water during the first few days. However, the lighter the soil the greater the total quantity that will be used in long periods of time. This is the opposite of the conditions with the vertical flumes and is worthy of note. The heavier the soil the less extended will be the wetted area with the lapse of time, which condition is as would be expected. That is, a sandy soil or a light soil will "sub" much farther in a horizontal direction than a heavy soil. The results indicate also that a heavy soil loses more water through evaporation when the soil is 10 or more inches deep than a sandy soil. This can be accounted for from the fact that the capillarity of the sandy soil is not sufficiently great to keep the surface wetted to the optimum capillary capacity for evaporation. It shows also the influence of gravity even in these horizontal flumes 10 inches in depth. Table 12 gives the percentage of the total distance moved and the percentage of the total water used in 30 days for different periods of time.

TABLE 12.—*Distance moved and water used, expressed in percentages of the total for 30 days.*

Number of days.	Flume.									
	20		31		50		70		90	
	Water.	Distance.	Water.	Distance.	Water.	Distance.	Water.	Distance.	Water.	Distance.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	17	....	22	27	26	28	18	29	17	21
3	30	33	36	46	42	45	30	....	29	34
5	38	42	42	56	51	....	36	52	37	44
10	53	64	58	73	67	69	52	70	53	62
15	67	69	70	84	78	80	64	81	67	74
20	81	82	81	91	86	87	79	88	81	84
30	100	100	100	100	100	100	100	100	100	100

The tables show what was to be expected, that relatively more water was required to advance the wetted area in the flume 1 inch near the end of the experiment than at the commencement of the experiment. This fact may be partially or wholly due to the loss of water by evaporation. However, from data secured with the vertical flumes it may be partially due to changes in the distribution of moisture through the length of the flumes.

Table 13 gives the average quantity of water, in cubic centimeters, required to advance the moisture in the flume 1 inch for different periods of time.

TABLE 13.—*Average use of water to advance the moisture 1 inch for different periods of time.*

Number of days.	Flume.					
	20	31	50	70	90	200
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	....	500	711	259	524	300
3	380	474	728	....	532	290
5	384	461	....	288	537	305
10	400	488	764	300	545	....
15	413	501	775	320	577	345
20	422	552	778	366	617	380
30	425	616	789	408	637	....

Since these flumes are open to evaporation, more water is required to advance the moisture an inch as the distance from the tank increases. In some instances the amount of moisture required to advance the wetted area 1 inch at the end of 30 days is nearly double that required the first few days. In the heavier types of soils, as represented by flume 50, a more constant quantity is required during each of the 30 days than for the lighter soils as represented by flume 70. Table 13 indicates also that less water is required to advance the moisture an inch in light soils than in heavy soils. In flume 31 more moisture was required per inch of advance during the first few days than during the fifth day, but after the fifth day there was a gradual increase in the moisture required. This same condition was found in flume 200. It is probable that this results from the fact that the moisture percentage changes to a very much greater extent near the tank end of the flume than it does toward the other end, and especially is this true the first few days. It is also noted from the results of the vertical flumes that for a distance of 14 inches above the surface of the water the moisture moves rather slowly upward. It is probable, therefore, that during a period along about the fifth day there is not sufficient moisture near the top of the flume to permit a maximum evaporation. After that time evaporation takes place more rapidly and hence the increase in water consumed. Another fact that will be brought out in the distribution of the soil moisture in these flumes is the gradual increase in the percentage of moisture throughout the wetted area of the flume from day to day, this constantly increasing percentage continuing until very near the point of capillary saturation.

In a review of Table 13 it is found that the order of the water requirements of these flumes at the end of the twentieth day, beginning at the one requiring the least water, is flume 70, 200, 20, 31, 90, and 50. Comparing this order with the order of the moisture equivalents of these soils, and beginning with the least moisture equivalent, we find the order just the same as above, except that flumes 70 and 200 are reversed. This interchange of place is probably accounted for by the fact that flume 200 would permit of more evaporation per square inch than would flume 70.

From the data in Table 13 it is possible to calculate for the horizontal flumes the quantity of water removed during any period of time, in cubic inches. Assuming the same rate of use in nature as in the flumes, the use of water by the soil in place can be calculated in acre-inches. In preparing Table 14 such assumptions were made.

TABLE 14.—*Loss of water from tanks in different periods of time. (Depth expressed in inches on an area of 100 square inches.*

Number of days.	Flume.					
	20	31	50	70	90	200
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	4.58	6.10	4.88	3.67	7.32	6.10
3	7.93	9.76	7.93	6.10	12.21	9.15
5	10.07	11.59	10.76	7.34	15.87	11.59
10	14.34	15.87	12.81	10.37	22.58	15.25
15	18.00	18.22	14.95	12.82	28.68	19.53
20	21.82	22.27	16.48	15.87	34.78	24.40
30	26.85	27.46	19.12	20.14	42.72	....

Table 14 is interesting from the fact that at the end of the first few days the use of water by the flumes containing the lighter soils is greater than for the flumes containing the heavier soils. The use of water by flume 50, containing the Whittier soil, is, after the first few days, considerably slower than that by flume 200, containing the light sandy Idaho soil. This fact is of importance and confirms the observations in nature of the excessive loss by capillarity in conveying channels constructed through sandy soils. This table, in connection with figure 3, indicates the extensive and long-continued capillary action in a horizontal direction in the lighter soils.

DISTRIBUTION OF MOISTURE IN HORIZONTAL FLUMES.

In considering the distribution of moisture in horizontal flumes open on top to evaporation, it is difficult to obtain uniform comparable results. This is due to the fact that the flumes were exposed to the natural changes of meteorological condition and many of them were in operation during the extremes of temperature. Another fact that is of primary importance is the effect of temperature upon the vertical distribution of moisture within the flume. With temperatures near the freezing point and with the soil containing about its maximum capillary capacity of moisture, a distribution of moisture is found in the soil differing materially from the distribution in the same soil with higher temperatures. It is not thought, therefore, of value in presenting a few data to attempt any specific calculations, but only general comments are made.

In Table 15 the first column gives the date on which the sample was taken; the second column gives the distance along the top of the flume, measured from the intersection of the top line of the flume and a vertical extension of the inside of the vertical part of the wick. This point is 19¼ inches above the water surface, measured along the upper side of the wick. The third column gives percentages of moisture at the various points for the top 5 inches of the flume, and the fourth column for the bottom 5 inches of the flume. The fifth column gives the average percentages of moisture at the various points.

Taking the average percentages of moisture in flume 31 at the same point and on different dates, it is found that the percentage of moisture gradually increases until the warmer weather in June. After that time there may be a slight decrease in percentages of moisture at the different points. Taking a sample at the 9-inch point, we find this to be true and that the percentage of moisture on June 10 had decreased about 2.2 per cent from what it was on May 23. Comparing the percentage of moistures for the top 5 inches of soil at the 9-inch point, we find that throughout the entire time there was a gradual increase in the percentage of moisture, while the bottom 5 increased in moisture content until April and then decreased.

TABLE 15.—*Distribution of moisture in horizontal flumes.*

FLUME 20.

Date.	Distance.	Top 5 inches.	Bottom 5 inches.	Average.
	Inches.	*Per cent.*	*Per cent.*	*Per cent.*
Apr. 18..	3	25.72	23.04	24.38
	9	20.21	21.45	20.85
	21	19.80	21.82	20.81
	45	17.00	19.44	18.22
	69	15.74	17.66	16.70
	81	12.00	16.47	14.24
	93	13.34	15.03	14.18
	105	11.52	13.21	12.36
	111	10.30	10.78	10.54
	117	8.36	6.76	7.56

FLUME 31.

Date.	Distance.	Top 5 inches.	Bottom 5 inches.	Average.
Apr. 20..	9	21.29	22.96	22.12
	15	20.42	21.66	21.04
	21	18.99	20.00	19.50
Apr. 29..	9	23.02	25.49	23.75
	15	23.02	24.52	22.39
	27	21.82	22.96	22.39
	33	18.98	21.84	20.41
May 23..	9	23.66	25.07	24.36
	33	20.39	22.76	21.57
	51	18.45	20.18	19.31
	59	16.43	17.76	17.09
June 10 .	9	23.72	21.98	22.85
	22	22.55	23.65	23.10
	34	19.77	22.74	21.25
	52	18.35	20.64	19.50
	64	13.81	17.88	15.85

FLUME 50.

Date.	Distance.	Top 5 inches.	Bottom 5 inches.	Average.
Sept. 21.	3	43.31	45.86	44.58
	12	44.50	42.52	43.61
	24	39.16	41.82	40.49
	30	38.92	39.94	39.43
	33	35.65	37.01	36.33

FLUME 70.

Date.	Distance.	Top 5 inches.	Bottom 5 inches.	Average.
	Inches.	*Per cent*	*Per cent.*	*Per cent.*
Oct. 14..	3	13.80	14.60	14.20
	30	4.59	9.62	7.10

FLUME 90.

Date.	Distance.	Top 5 inches.	Bottom 5 inches.	Average.
Jan. 29..	½	28.80	28.81	28.80
	18	26.37	26.66	26.52
	42	19.30	20.07	19.69
Feb. 29..	½	30.53	29.15	29.84
	18	28.44	27.87	28.15
	42	25.44	25.04	25.24
	72	18.81	19.75	19.28
Feb. 22..	½	32.30	29.83	31.07
	9	30.22	27.49	28.85
	18	28.35	26.17	27.21
	30	26.76	26.05	26.40
	42	25.86	25.27	25.57
	54	25.35	25.58	25.47
	72	17.65	23.33	20.49
	84	22.35	22.80	22.57
	96	18.53	19.87	19.20
Mar. 5...	½	31.53	29.52	30.52
	18	27.44	26.30	26.87
	42	26.33	25.66	25.99
	72	23.37	23.67	23.52
Mar. 10..	37½	26.50	26.00	26.25

FLUME 200.

Date.	Distance.	Top 5 inches.	Bottom 5 inches.	Average.
Apr. 7...	3	11.92	16.28	14.10
	4	12.50	18.25	15.37
	28	10.37	11.95	11.34
	46	14.61	16.71	15.66
	64	9.59	13.00	11.30
	End.	4.43	5.02	4.72

In flume 90 the same conditions are found as in flume 31, except that during the months of January and February there is an apparent discrepancy in the percentages of moisture in the bottom 5 inches and the top 5 inches of soil. This apparent discrepancy is probably the result of temperatures below the freezing point and will be considered in a subsequent part of this report in connection with other similar analyses.

All of the flumes show a gradual decrease in the percentage of moisture from the tank end of the flume to the outward extremity of the wetted area. In flume 20, the average percentage of moisture decreases at the rate of approximately 1.75 per cent for each linear foot between the third and eleventh feet. In flume 50 the rate of decrease is about 2.2 per cent per linear foot. The rate of decrease varies in these flumes, as would be expected not only from the different meteorological conditions when the experiments were run, but also from the character of the soil.

FLUMES INCLINED DOWNWARD FROM THE HORIZONTAL.

The flumes in which it was intended that gravity should assist the capillary movement of moisture were inclined downward at various angles from the horizontal. In all the flumes inclined in this way the movement of the moisture and the amount of water used were greater than for the horizontal flumes or the flumes inclined upward from the horizontal. The extent to which water would move in the inclined flumes where the inclination downward was 10 degrees or more was, in most cases, beyond the limits of the equipment used. Most of the experiments were carried to such an extent as to warrant certain conclusions. The extent of this movement in the open flumes appears to be limited not by the friction factors, but by the power of the wick to supply moisture in sufficient quantity to take care of the evaporation from the flume. That is, were evaporation eliminated, the extent of movement in the flumes inclined downward at angles greater than 30 degrees, except for the very heavy soils, would be far beyond experimental limits. In the case of the very heavy soils, as typified by the Whittier type, there were indications that in the less steeply inclined flumes friction played its part here as well as in the horizontal flumes.

In distribution of moisture there are found some differences between these flumes and either the vertical or the horizontal; and, as will be shown later free water was developed in the flumes inclined downward.

SOILS USED.

Table 16 gives the numbers of the flumes and the soil contained in each:

TABLE 16.—*Soils in flumes inclined downward.*

Number of flume.	Description.
4	Decomposed granite soil from Riverside, Calif.
34	Decomposed granite and clay from Riverside, Calif.
54	Heavy clay soil from Whittier, Calif.
74	Sand and gravel soil from Uplands, Calif.
94	Lava ash from Idaho.
204	Sandy soil from Idaho.

Figure 4 gives the dates and measurements for the movement of moisture in flumes inclined at an angle of 30 degrees and open on top to evaporation. The horizontal element is the time and the vertical element the distance in inches.

A comparison of figure 4 with figure 2 shows very strikingly the part gravity plays in capillarity. It shows to what extent gravity aids or retards the movement of soil moisture by capillarity. Another striking feature is the comparative uniformity of the rate of movement of the moisture after the first three or four days. While there is a general slowing down of the rate at which moisture advances from day to day, it is so much less marked in these flumes than in the flumes discussed in previous sections as to be of comparatively little moment.

It is observed that after the first day or two the type of soil used in the flumes is of greater importance in limiting the extent of the movement of the moisture. The more open and porous the soil, the more rapid and extended the movement of the moisture. For instance, in the sandy Idaho soil of flume 204, the moisture advanced as far in one day as it would in the heavy Riverside soil in five and one-half days and 50 per cent farther in the first day than it would in the heavy Whittier soil in 30 days. In flume 204 the only limit to the extent of the movement of moisture was the ability of the wick to furnish the moisture. However, the porosity of the soil is not the only factor, but the transporting power of the soil itself is of prime importance. For instance, comparing flume 34 (heavy Riverside) with flume 74 (Upland), flume 34 has the greater rate of movement of moisture at all times within the limits of the experiment, and yet the soil of flume 74 has the greater porosity. The difference in the rate of movement in these two soils appears to be due to the difference in the capillary power of the wick to transmit the water from the tanks to the flumes proper. Had there been less vertical lift from the tank to the flume by the wick, flume 74 would undoubtedly have shown the greater rate of moisture movement. The effect of porosity is well illustrated in flumes 74 and 94. The soil in flume 94 has the greater porosity, and while the rate of movement of the moisture is less in this flume for the first week, it has the greater rate of movement thereafter. Again, comparing flumes 4 and 34, the soil in flume 4 has the greater porosity, but the soil in flume 34 the greater capillary power, and after the first two weeks the rate of movement of moisture in flume 34 is greater.

In table 17 is given the extent of movement of moisture as shown in figure 4, in percentages of the extent of movement in flume 34.

That is, in flume 34 the moisture had moved the first day 26 inches, or 100 per cent. In flume 4 the moisture had moved the first day 28.85 inches, or, as compared with the movement of moisture in flume 34, 111 per cent, while in flume 54 the moisture had moved 10.7 inches, or, based on the movement in flume 34, 41 per cent. Flume 34 maintained a relatively higher rate of movement of moisture than

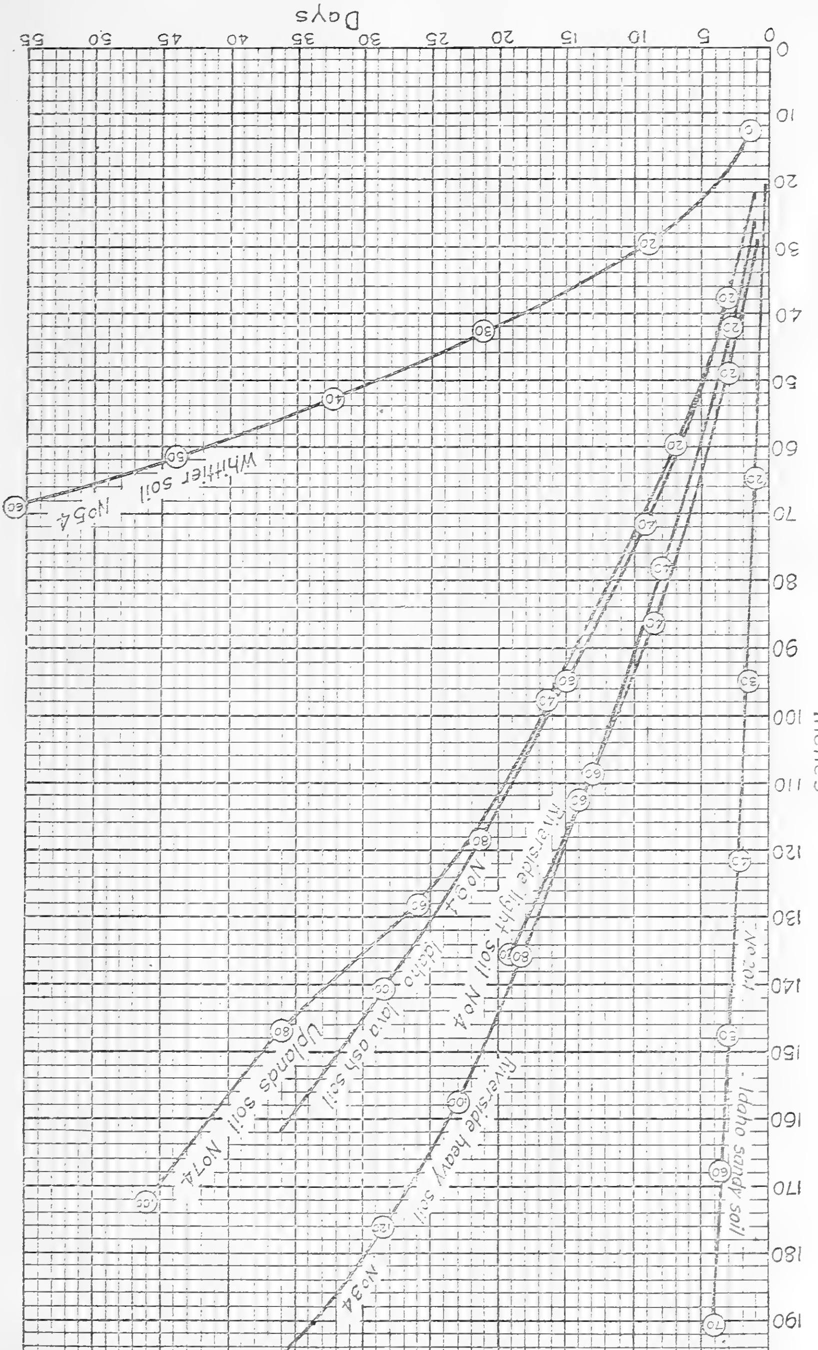

FIG. 4.—Rate of movement of moisture in open flumes inclined downward at thirty degrees from the horizontal. Figures in circles indicate points at which that number of liters of water had been taken up.

any other flumes, although flume 94 maintained nearly the same rate after the first day. In view of the fact that these flumes were operated at different seasons of the year, it is not possible to say to what extent the variable meteorological conditions might have influenced the results.

TABLE 17.—*Comparative movement of moisture, in percentages of movement in flume 34.*

Number of days.	Flume.				
	4	34	54	74	94
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	111	100	41	85	82
3	111	100	42	87	85
5	108	100	39	87	87
10	102	100	34	79	83
15	99	100	31	78	78
20	....	100	29	78	78
30	....	100	27	75	80

In Table 18 there is shown for each flume the percentage of the total distance moved in 30 days that had been moved in 1, 3, 5, 10, 15, and 20 days.

Table 18 shows in another way what has been previously stated. The heavier soil and less porous soils show a relatively greater percentage of movement of moisture the first day or two and a relatively slower rate of movement the last few days. The lighter and more porous soils show the more uniform and more extended movement of the moisture. It is found that in all the flumes, in 5 days, or one-sixth of the 30 days, more than one-third of the total 30-day distance was traveled; in 10 days, or one-third of the time, more than one-half the distance has been traveled, and in 20 days, or two-thirds of the time, more than four-fifths the distance has been covered.

In the discussion previously given of these flumes only the 30-day limit of time was used. However, in figure 4 the curve for flume 54, the heavy Whittier soil, shows that after 30 days the rate of movement of the moisture continues to grow less and less every day, although there is considerable uniformity in the rate of decrease of movement. The figures would indicate that the movement of moisture would reach a considerably greater distance than that shown upon the figure. It is seen that in flume 74 (Upland soil) after 47 days the rate of movement of the moisture is not much less than it was at 30 days, and the evidence is that the moisture would continue to move in this flume rather indefinitely; especially would this be true were evaporation prevented.

TABLE 18.—*Movement of moisture by days, in percentages of total movement in 30 days.*

Number of days.	Flume.			
	34	54	74	94
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	14	22	16	15
3	28	37	29	26
5	32	46	37	35
10	50	62	53	52
15	65	74	68	65
20	79	85	82	80
30	100	100	100	100

WATER USED.

The figures in the small circles show in liters the water used by these flumes. The water used by flumes inclined downward is, like the movement of the moisture, greater than for the horizontal or vertical flumes. A striking feature is the rather uniform use of a comparatively constant quantity of water after the second or third day. The rate of use is more constant and uniform than for the vertical or horizontal flumes. Flume 34 had used on the tenth day about 4 liters of water; on the twentieth day about 8 liters; on the thirtieth day about 11.5 liters; and on the fortieth day about 14 liters. In flume 54 with the heavy Whittier soil an even greater uniformity is observed. In this flume there was used approximately the same quantity of water every day after the sixth day up to the fifty-seventh day, or at the end of the experiment. The same uniformity is found, in fact, in nearly all of the other flumes. One fact worth special notice is that the use of water by the flume as represented by the loss of water from the tanks is that evaporation does not appear to have varied the use to any extent. This is true though the same flume was exposed to almost all the different and variable weather conditions found at Riverside. To show the relative uniformity in the rate of use of water by some of these flumes Table 19 has been prepared.

Table 19.—*Water used, by days, in percentages of total use in 30 days.*

Number of days.	Flume.			
	34	54	74	94
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	9	22	10	11
3	18	35	19	20
5	23	43	25	28
10	39	57	41	43
15	54	68	55	57
20	71?	78	68	70
30	100	100	100	100
40	121	127	129	----------
50	----------	149	----------	----------

Table 19 shows that the heavier soils use relatively more water at the commencement than near the end of the experiment. It shows, also, a more uniform use by the heavier soils. It shows, for instance, that the soil in flume 54 had used relatively more than twice as much water as any other flume at the end of the first day, while on the fifteenth day it had used relatively only about one-fifth more than the others. Table 20 shows the amount of water required at different periods of time to advance the moisture in the flumes an average distance of 1 inch. For instance, on the third day, flume 24 had used 18 liters of water and the moisture had advanced 44.15 inches, or an average of 479 cubic centimeters of water was required per inch.

A comparison of the figures in Table 20 with the moisture equivalents of the soils appears to show no close relation. However, in a general way the greater the moisture equivalent the greater the quantity of water required to advance the moisture 1 inch. It is observed in nearly all of the flumes that less water is required per inch about the third day than at any other time. In all cases, however, more water was required per inch at the end than was required at the beginning of the experiment. It is observed that for soils of the heavier type represented in flume 54, for some time after the commencement of the experiment less water is required per inch than for the following day, but after about the thirtieth day there is a very rapid increase of the water requirements. It is probable that there is some concentration of moisture at the top of the vertical lift before the moisture changes direction to the inclined part of the flume and that this moisture is partially drawn upon to advance the moisture in the inclined part of the flume. After a few days this surplus supply, if such it may be called, is exhausted and then the moisture to advance the wetted area in the flume can be derived only from the supply in the tank. It must be kept in mind also that with the lapse of time a greater wetted area is exposed to evaporation, and this in itself would account for some additional water requirement per inch. In some cases the water requirement per inch at the end of the fortieth day was about double the requirement the first day, but in the heavier soils this is not so pronounced.

TABLE 20.—*Water used to advance moisture 1 inch at different times, in cubic centimeters.*

Number of days.	Flume.					
	4	34	54	74	94	204
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	319	385	743	290	566	311
3	346	447	707	338	562	360
5	425	498	700	336	571	....
10	450	533	677	364	597	....
15	545	569	680	411	634	....
20	....	607	697	419	647	....
30	....	684	735	507	724	....
40	....	....	806	567	....	....
50	....	....	846	....	....	....
57	....	....	884	....	....	....

FLUMES INCLINED UPWARD FROM THE HORIZONTAL AT AN ANGLE OF 15°.

To throw some light upon the effect of a relatively small inclination of the flumes upward from the horizontal, the data will be given and discussed for the flumes inclined upward at an angle of 15° and open on top to evaporation. The flumes are the same in every respect as the others, except the angle of inclination. In these flumes there is a vertical lift of 4 inches before a change is made in the direction of the flumes.

They show a much less movement of the moisture and a much less use of water than the horizontal flumes, but a more extended movement of the moisture and greater use of water than the vertical flumes.

SOILS USED.

Table 21 gives a list of the flumes inclined upward at an angle of 15° and soils contained in each.

TABLE 21.—*Soils in flumes inclined upward at an angle of 15°.*

Number of flume.	Description.
39	Decomposed granite with clay from Riverside, Calif.
58	Heavy clay soil from Whittier, Calif.
76	Sand and gravel soil from Upland, Calif.
96	Lava ash from Idaho.
206	Sandy soil from Idaho.

MOVEMENT OF MOISTURE.

Figure 5 gives the distance the moisture had moved in the flumes at the end of the time indicated. The horizontal element is the time in days and the vertical element is the distance in inches.

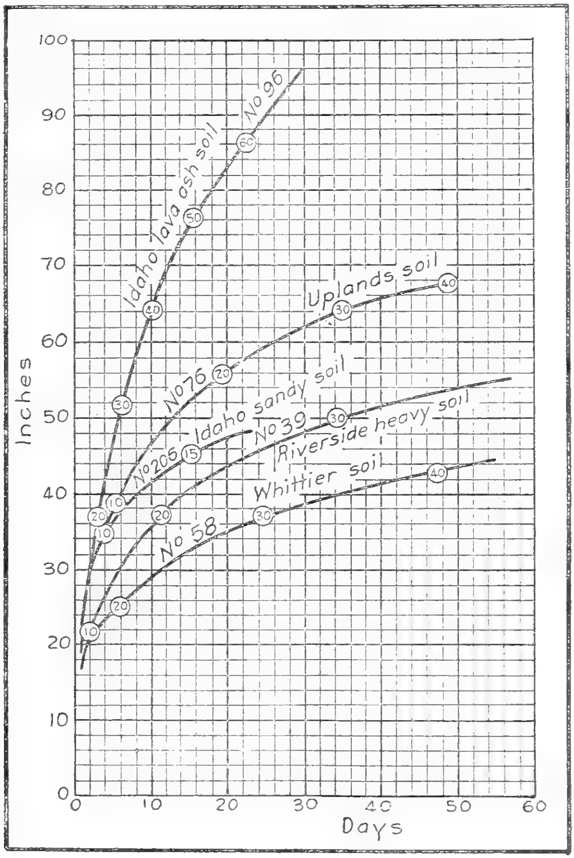

FIG. 5.—Rate of movement of moisture in open flumes inclined fifteen degrees upward from the horizontal. Figures in circles indicate the points at which that number of liters of water had been taken up.

From figure 5 it is seen that the curves for the movement of moisture have the same parabolic form as the curves in the preceding figures. A comparison of these curves with those for the vertical and horizontal flumes shows the importance of gravity in the rate and extent of movement of moisture by capillarity.

The curves show that the rate of movement of moisture is rather more uniform over an extended period than in the vertical flumes. After the first two or three days there is a gradual slowing down of the rate of movement from day to day. Where the experiment is carried on for 50 days or more it is observed that the rate of movement is very slow at that time.

TABLE 22.—*Extent of moisture movement in flumes at various times.*

Number of days.	Flume.			
	39	58	76	96
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	34	30	30	21
3	51	53	53	37
5	59	59	61	48
10	74	75	75	66
15	83	84	84	78
20	90	91	90	86
30	100	100	100	100
40	106	108	106	....
50	112	....	109	....

Table 22 gives the extent of the movement of the moisture at various times, in percentages of the movement in 30 days.

It is observed from Table 22 that the relative rate of movement in the first three flumes day by day was about the same. In flume 96, however, the rate of movement of the moisture was relatively not so great during the forepart of the experiment, but that a more uniform rate of movement was maintained throughout. In the first three flumes more than one-half of the total 30-day distance had been traveled in three days, or one-tenth of the time, and in two-thirds of the time more than nine-tenths of the 30-day distance had been traveled. In flume 96 on the third day only about one-third of the distance had been traveled, and it was not until about the sixth day that one-half of the distance had been traveled.

TABLE 23.—*Relative movement of moisture, by percentage of movement, in flume 96.*

Number of days.	Flume.				
	39	58	76	96	206
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	80	56	90	100	117
3	69	56	91	100	90
5	62	50	82	100	80
10	57	46	73	100	66
15	54	44	70	100	60
20	53	43	68	100	57
30	50	40	65	100	....

From Table 23 it is found that on the thirtieth day the moisture in flume 58 had moved but 40 per cent as far as in flume 96, while in flume 39 the moisture had moved one-half as far as in flume 96.

All of these flumes when compared with flume 96 show a lesser relative movement during the latter part of the experiment than during the forepart of the experiment. This table shows also that the heavy soil as represented in flume 58 has a much less rapid rate of movement during the forepart of the experiment, but that the rate of movement as compared with flumes 39 and 76 is more uniform. The figures for flume 206 show the rapid decrease of rate of movement of the moisture from day to day.

WATER USED.

The amount of water used in the flumes inclined upward is greater than for the vertical flumes and less than for the horizontal flumes. The total quantity of water used by the flumes inclined at an angle of 15° upward from the horizontal is given in liters in figure 5 in the small circles. Table 24 gives the total quantity of water, in liters, used by the different flumes at the end of different periods of time. The same information is given in Table 25, in percentages based upon the quantity of water used by each flume at the end of the thirtieth day.

TABLE 24.—*Water used by flumes at different periods of time.*

Number of days.	Flume.				
	39	58	76	96	206
	Liters.	*Liters.*	*Liters.*	*Liters.*	*Liters.*
1	7.5	10.5	5.0	11	7.0
3	13.0	15.0	8.0	20	9.0
5	15.5	19.0	10.0	27	10.5
10	19.0	23.0	14.0	39	13.5
15	22.0	25.5	17.0	48	14.75
20	24.5	28.0	20.5	56	15.75
30	27.5	32.5	26.25	65	....
40	31.25	36.75	33.0	....	....
50	35.0	41.0	40.0	....	....

This table shows that the heavier soils as represented in flumes 39 and 58 use relatively more water during the first few days of the experiment than do the lighter soils. In the heavier soil about the fourth day 50 per cent of the total quantity of water used in 30 days had been used, while for the lighter soils there had been used on the fourth day only about one-third the quantity used in 30 days.

TABLE 25.—*Water used, by days, in percentages of total used in 30 days.*

Number of days.	Flume.			
	39	58	76	96
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	27	32	19	17
3	47	41	31	31
5	57	59	38	41
10	69	71	53	60
15	80	78	64	74
20	90	86	78	86
30	100	100	100	100
40	114	113	125	....
50	121	126	152	....

Table 26 gives the average quantity of water removed from the tanks at different periods of time to advance the moisture in the flumes an average distance of 1 inch. That is, in flume 39 at the end of the fifth day there had been removed from the tank 15.5 liters of water and the moisture had advanced in the flume a total distance of 28.55 inches, or there had been used an average of 543 cubic centimeters of water for each inch the moisture had advanced.

Table 26 shows that in the lighter soils the quantity of water used near the beginning of the experiment was very much less than the quantity of water used during the last part of the experiment. In flume 76 at the end of the fiftieth day there was used twice as much water per inch as for the first day. In flume 39 there is shown after the third day somewhat of an increase in the use of water from day to day, but it is much less marked than in any of the other flumes. In flume 96 the use of water on the thirtieth day is about 25 per cent in excess of the use on the first day. The increase in the quantity of moisture required per inch with the lapse of time is probably due largely to the effect of evaporation. In flume 58 the distribution of moisture was so uniform as compared with the other flumes that the quantity of water in the flume per inch throughout its length is almost the same, with the exception of the upper few inches. In the other flumes there is a marked decrease in the percentage of moisture from near the tank to the outer extremity of the flume. The relation of the figures in this table to each other corresponds very closely with the relation of the moisture equivalents for the soils represented.

TABLE 26.—*Water used per inch of advance.*

Number of days.	Flume.				
	39	58	76	96	206
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	406	816	272	541	297
3	530	835	245	558	278
5	543	826	266	589	290
10	531	786	302	617	325
15	556	782	327	644	301
20	573	792	366	679	348
30	548	840	423	676	
40	605	891	487		
50	686		589		

To show the amount of water removed from the tanks by the flumes expressed in depth in inches on an area equal to the cross section of the flumes, Table 27 is presented.

TABLE 27.—*Water removed from the tanks by capillarity expressed in depth on an area equal to the cross section of the flume.*

Number of days.	Flume.				
	39	58	76	96	206
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	4.58	6.41	3.05	6.71	4.27
3	7.93	9.15	4.88	12.20	5.49
5	9.44	11.59	6.10	16.47	6.41
10	11.59	14.03	8.54	23.79	8.24
15	13.42	15.56	10.37	29.28	9.00
20	14.95	17.08	12.51	34.16	9.61
30	16.78	19.83	15.99	39.65	
40	19.06	22.42	20.13		
50	21.35	25.01	24.40		

At the end of the thirtieth day it was found that the flumes had taken from the tanks sufficient water to cover the cross section of the flumes to a depth of from 16 to 40 inches. That is, where the rate of loss is the same over the area of an acre as over the area represented by the flumes, then in 20 days the acre of soil represented in flume 39 would have removed from the underground water 16.78 acre-inches of water, while the soil represented by flume 96 would have removed 39.65 acre-inches of water, or a little more than twice as much. These tables are valuable in that they give an indication of the quantity of water that may be removed from underground water sources by capillary action of the soil. It must be kept in mind, however, that in the case of the flumes evaporation and capillarity are acting at the same time.

DISTRIBUTION OF MOISTURE.

The distribution of moisture in the flumes inclined upward at an angle of 15° does not differ materially from the distribution in the vertical flumes. In Table 28 is given the distribution of moisture in flume 96 at various times. It will be noticed that in this table, as in that for the vertical flumes, there is rather a uniform constant quantity of moisture near the lower end and then a gradually decreasing amount toward the top of the flume. The rates of decrease, however, are not comparable as far as the figures in this table and those for the other flumes indicate.

TABLE 28.—*Distribution of moisture in flume 96.*

Distance.	Percentage of water.		
	Top 5 inches.	Bottom 5 inches.	Average.
Inches.	*Per cent.*	*Per cent.*	*Per cent.*
28	28.32	29.66	28.99
40	28.56	27.89	28.22
52	26.70	26.26	26.48
64	24.83	24.87	24.85
76	25.06	24.20	24.63
88	21.71	21.96	21.83
94	20.58	20.95	20.77
100	17.25	17.73	17.49

In the open flumes there are several factors which account for a lack of uniformity in the distribution of moisture other than the mere fact of elevation above the surface of the water. The rate of evaporation is different for different points of the flume due to differences in moisture content of the soil (18). The concentration at the surface of the soluble salts of the soil, which will be different at different points throughout the flume, would cause some difference in the moisture content due to lessening evaporation.

EFFECT OF GRAVITY ON THE MOVEMENT OF SOIL MOISTURE BY CAPILLARITY.

TABLE 29.—*Number of flume and angle of inclination.*

No. of flume.	Angle of inclination.
34	30° downward.
32	15° downward.
31	Horizontal.
39	15° upward.
42	45° upward.
43	Vertical.

As stated in this report, the plan was to have capillarity act in the direction of gravity, in a direction opposed to gravity, and in a horizontal direction in which gravity was eliminated as far as possible. To give an idea of the influence of gravity in the movement of soil moisture by capillarity there are given below data on a complete set of flumes containing the heavy Riverside soil. While the other soils show considerable variation, these variations are almost entirely in degree and it is not thought that the addition of these data to this report would be of any material benefit. Table 29 gives a list of the flumes in the set under consideration and their angles relative to the horizontal.

There was in this set an additional flume inclined downward at an angle of 45°, but the results from that flume were so near like those of the flume inclined at an angle of 30° downward that the addition of the data from this flume would be confusing without adding to the value of the information. In fact, the flume inclined downward at an angle of 45° was discarded after the third set of experiments, for the reason that it did not add to the information obtained from the flume inclined downward at 30°.

Figure 6 gives the results of the daily measurements of the movement of moisture in the several flumes. Table 30 gives the distance the moisture had moved at different periods of time from 1 to 40 days.

TABLE 30.—*Distance moisture had moved at various times, in flumes placed at different angles.*

Days.	Flume.					
	34	32	31	39	42	43
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	26.00	22.05	20.00	16.35	16.75	15.70
3	44.15	41.30	33.75	24.55	24.40	20.75
5	58.25	55.00	41.20	28.55	28.85	22.82
10	91.05	8.85	53.30	35.80	32.90	26.25
15	118.65	105.20	61.40	40.25	34.65	28.05
20	144.05	125.45	66.15	43.65	36.05	29.40
30	181.25	153.55	75.80	48.40	37.50	31.55
40	....	168.35	79.85	51.25	38.75	33.15

Table 30 and figure 6 show very strikingly the effect of gravity on the capillary movement of soil moisture even at the end of the first day. It is obvious that in the horizontal flume the distance the moisture had moved is less than in either of the flumes inclined downward and is greater than for those inclined upward. This relation holds true not only for the first day but for all the time up to 40 days. The table shows that the movement of moisture is less extended in flumes inclined downward 15° than it is in flumes inclined downward 30°, but that the difference is not nearly so marked as is the difference between the 30° flume and the horizontal one. Flumes 31 and 32 show very clearly the effect of a relatively slight inclination downward from the horizontal.

For instance, on the thirtieth day the moisture has moved in flume 32 a little more than twice as far as in flume 31. The figures presented above and the figures obtained for the flumes inclined downward at an angle of 45° indicate that at least after an angle of 15° is obtained the effect of inclination is not nearly so marked, degree by degree, as for the first 15° of inclination. Comparing the horizontal flume with the flume inclined upward, we find that even on the first day the inclination is a marked factor in the extent of the movement

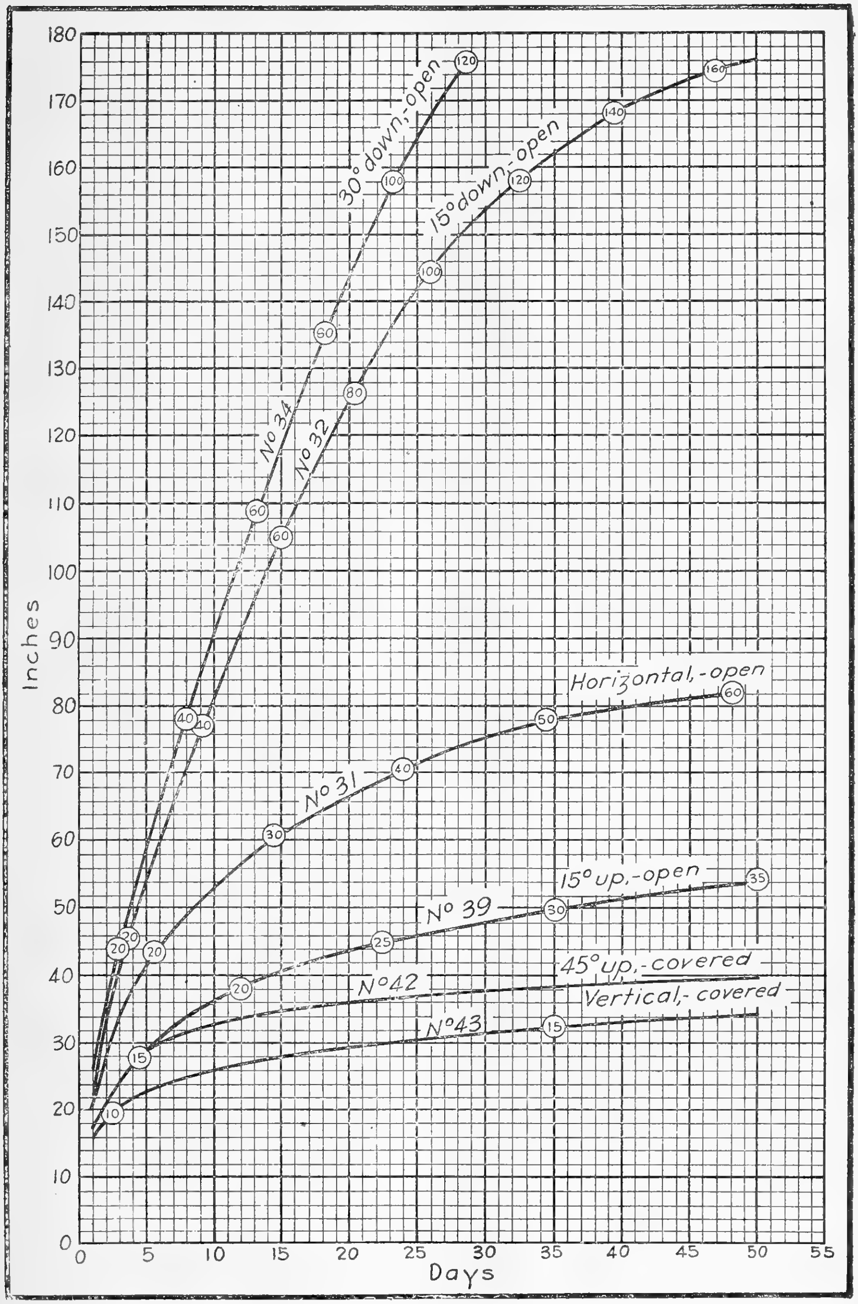

FIG. 6.—Rate of movement of moistue in set of flumes at various slopes each containing Riverside heavy decomposed granite loam soil. Figures within circles indicate point at which that number of liters of water had been taken up.

of the soil moisture. At the end of the thirtieth day we find that the flume inclined upward at 45° gives only one-half as extensive a movement of the soil moisture as the horizontal flume, and the flume inclined upward at an angle of 30° gives about two-thirds as extensive a movement of the soil moisture. Taking the four flumes, the horizontal, the one inclined upward at 30°, the one inclined upward at 45°, and the vertical flume, the extent of soil moisture in distance within these flumes is in the order given, with the greater extent of moisture in flume 31 or the horizontal flume.

To show more clearly the effect of gravity upon the movement of moisture by capillarity, Table 31 gives the data of Table 30 in percentages of movement in the flume inclined downward 30°:

TABLE 31.—*Relative movement of moisture in flumes, expressed in percentages of movement in flume 34.*

Number of days.	Flume.					
	34	32	31	39	42	43
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	100	85	80	63	64	60
3	100	93	76	56	55	47
5	100	94	71	49	49	39
10	100	90	59	39	36	29
15	100	90	52	33	29	24
20	100	87	46	30	25	20
30	100	85	42	26	21	12

On the thirtieth day we find that the moisture in the vertical flume has moved but 12 per cent as far as in flume 34 and in flume 42 it has moved 21 per cent as far; in flume 39, 26 per cent as far; in flume 32, 85 per cent as far; and in flume 31, 42 per cent as far. It is obvious that the above percentages are comparable to the angles of inclination relative to the horizontal. This table brings out even more strikingly the effect of gravity in the movement of soil moisture by capillarity.

Table 32 gives the relative distance the moisture had moved in the several flumes for different periods of time, based on the distance the miosture had moved in 30 days in the respective flumes.

TABLE 32.—*Capillary movement of moisture at various times, in percentage of the movement in 30 days.*

Number of days.	Flume.					
	34	32	31	39	42	34
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	14	14	26	34	45	50
5	32	36	54	59	77	72
10	50	53	70	74	88	83
15	65	68	81	83	92	90
20	79	79	87	90	96	93
30	100	100	100	100	100	100

The striking feature of Table 32 is the fact that as the flumes recede from the vertical the rate of movement day by day is more uniform and more constant. In the flume inclined downward at an angle of 30° the extent of movement of moisture on the fifteenth day or one-half the time was 65 per cent of the total movement of the moisture in 30 days. In flume 32 this percentage was 68. In flume 31 or the horizontal flume it was 81 per cent; in flume 39 it was 83 per cent; and in the flume with a vertical angle of 45° it was 92 per cent.

To present the above data in a more condensed form, figure 7 has been prepared.

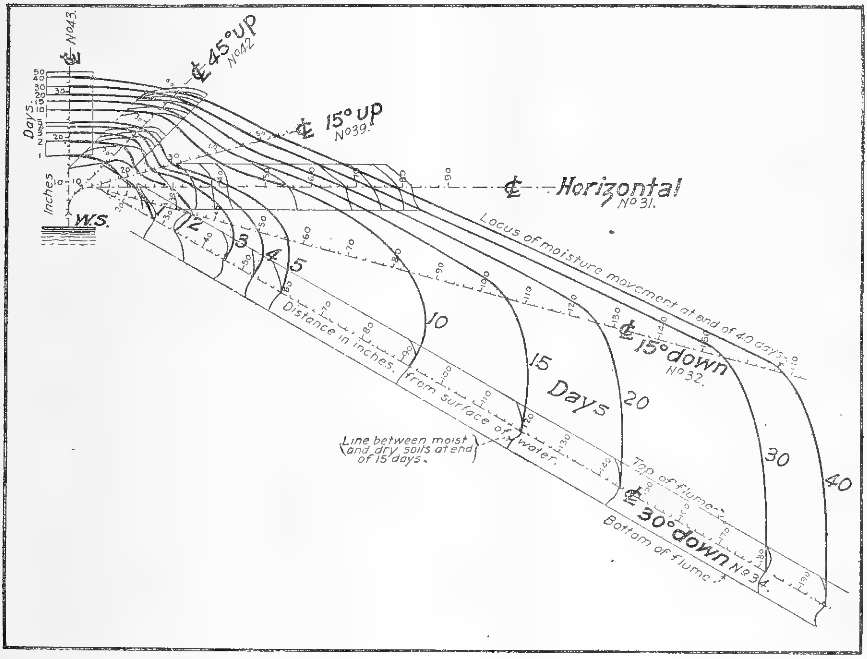

FIG. 7.—Comparison of rate of movement of moisture in flumes of various slopes; all flumes containing Riverside heavy decomposed granite loam. Also shows appearance of moisture curves from top to bottom of flumes, except Nos. 32 and 39.

Figure 7 shows the relative positions of the moisture in the various flumes with reference to the surface of the water in the tanks at various times during the experiment. The lines on the drawing showing the direction of the flumes represent the longitudinal axes of the flumes along their center lines. The figures show the directions and the paths through which the moisture from the tanks must travel along the center lines of the flumes. It is obvious that during the forepart of the experiment the lines joining the points representing the positions of the moisture on the different dates are very irregular. It shows that there is a tendency of the curve joining these points to become more uniform in outline as the experiment continues for longer periods of time. That is, the line joining the points representing the position of the moisture on the thirtieth day is more regular and uniform than is the line joining the points for the position of the moisture on the first day. The figure indicates that with the lapse of an extended period of time the line joining the points representing the extreme extent of moisture would be of a parabolic form. This curve would have a rather limited extent in the vertical direction upward, but the longitudinal extent and the extent downward from the vertical might be infinity. Even with evaporation a factor, these last two named distances are relatively very great as compared with the vertical elements. The drawing emphasizes and portrays more clearly than do the figures the importance of gravity in the movement of soil moisture by capillarity. These deductions are of importance from the economic point of view in that they show very clearly what may be the distribution of moisture within the soil of water applied upon sloping ground. It indicates, for instance, that the extent of distribution of moisture down a slope would be much greater than it would be up a slope. A comparison of the data for these flumes indicates how great would be the loss of water in conveying channels through capillary action where the conveying channels traverse ground having a transverse slope. These data would indicate that on the lower side of the channel capillary action would continue taking water from the channel in about the same quantity for an indefinite period of time, while on the upper side the loss of water through capillarity would be very much less in quantity and in extent of time through which it would act. These figures indicate further the importance of slope of the strata of alluvial soil, both in reference to conveying channels and impounding reservoirs. In other words, these data indicate that with any appreciable slope downward of the strata, capillary action continues indefinitely.

WATER USED.

In considering the quantity of water used by the several flumes from the vertical upward to the 45° downward from the horizontal, it is found that the inclination of the flume is a most potent factor in determining the quantity of water that will be removed from the tanks. The data for these flumes indicate clearly the effect of gravity in the movement of water as soil moisture by capillary action. A difference in inclination may mean, and most frequently does mean, a difference between practically no movement of soil moisture and a movement of an appreciable relatively constant quantity of water.

The figures within the small circles in figure 6 give in liters the quantity of water removed from the tanks.

An examination of these data shows that the flumes inclined upward from the horizontal use a relatively large quantity of water during the first two or three days and that after that time a relatively small quantity of water. Near the end of the 30-day period very little water is taken up by these flumes. With the flumes inclined downward from the horizontal a somewhat larger quantity of water is used during the first three or four days than thereafter. However, these flumes after about the fourth or fifth day use a rather constant uniform quantity of water for an indefinite period of time within the limits of these tests. Table 33 gives the total quantity of water in liters used by the several flumes for different periods of time and shows in a more condensed form the data presented in figure 6, and that on the thirtieth day a vertical flume had used but 15 liters of

TABLE 33.—*Total quantity of water used at various times, in liters.*

Number of days.	Flume.					
	34	32	31	39	42	43
1	10.0	9.5	10.0	7.5	10.0	7.0
3	20.0	18.0	16.0	13.0	14.0	10.5
5	29.0	25.0	19.0	15.5	16.0	11.1
10	48.5	42.0	26.0	19.0	19.0	12.4
15	67.5	59.0	31.5	22.0	21.5	13.5
20	87.5	78.5	36.5	24.5	23.75	13.8
30	124.0	112.0	45.0	27.5	28.5	15.0
40	150.0	140.5	53.0	31.25	30.5	15.8

water, while a flume inclined downward at an angle of 30° had used 124 liters, or about eight and a third times as much. The table also shows that, with the exception of flumes 39 and 42, the quantity of water used by each flume was in the order represented by the inclination of the flume from the vertical downward. This table shows that for the flumes inclined downward at angles of 15° and 30° there was not such a great difference in the total quantity of water used. In other words, it would appear that for the flume inclined downward at an angle of 15° the capacity of the wick to furnish moisture to the flume from the tank had been about reached. In the two flumes 39 and 42, or those inclined up at an angle of 15° and 45°, respectively, we find not much difference in the quantity of water used. Just why this condition does exist in this case, there are not sufficient data to indicate clearly. However, flume 42 contains a relatively higher per cent of moisture than does flume 39. This of itself is not quite sufficient to account for the difference.

On the fortieth day flume 43 had removed from the tank the equivalent of 9.64 inches, and flume 34 had removed the equivalent of 91.58 inches. These figures are striking in that they show what effect the slope of the ground has in assisting capillarity to draw water from conveying channels and storage reservoirs.

TABLE 34.—*Quantity of water removed from the tanks at various times, expressed in depth, on an area equal to cross section of flume.*

Number of days.	Flume.					
	34	32	31	39	42	43
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	6.11	5.65	6.11	4.58	6.11	4.28
3	12.22	10.99	9.76	7.93	8.54	6.41
5	17.72	15.26	11.59	9.46	9.76	6.77
10	29.61	25.64	15.86	11.59	11.59	7.56
15	41.20	36.02	19.22	13.42	12.81	8.54
20	53.40	47.90	22.28	14.95	14.50	9.16
40	91.58	85.75	32.33	19.06	18.63	9.64

Table 35 gives the number of cubic centimeters of moisture required to advance the moisture in the flumes an average distance of 1 inch at different periods of time. One point worthy of note in this table is the fact that flume 43 used about the same quantity of water per inch throughout. It must be kept in mind that this flume was closed to evaporation and that no water escaped from this tank that was not confined within the wetted soil area of the flume. The other flumes were all open to evaporation. The figures seem to indicate that as we recede from the vertical the quantity of water required per inch is less. However, these figures are so confused with the evaporation that they do not indicate the true facts as to the requirement of the soil itself when placed at these different angles. The evaporation factor is confused, for the reason that the soil within the flume contains relatively different percentages of moisture, which has an influence upon the quantity of evaporation. Furthermore, the wetted area of soil differs so greatly in the several flumes and hence that the area exposed to evaporation is much different.

TABLE 35.—*Average quantity of water required to advance wetted area in flumes 1 inch.*

Number of days.	Flume.					
	34	32	31	39	42	43
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	385	419	500	406	596	446
3	447	436	474	530	573	506
5	498	455	477	543	578	486
10	533	513	488	531	587	482
15	569	561	501	556	629	487
20	608	626	562	573	663	471
30	684	739	616	548	760	476
40	....	843	681	605	767	476
50	....	....	....	686	....	....

EVALUATION OF EMPIRICAL CURVES.

In order to determine whether any mathematical relation could be found between the curves representing the movement of moisture in the different soils, mathematical equations to fit these empirical curves were found for typical flumes. The curves representing the movement of moisture in flumes at various slopes containing Riverside heavy decomposed granite loam were evaluated to ascertain whether the movement of moisture was a function of the angle of the slope.

The problem of finding a mathematical equation to fit a given curve is a tedious one. Since many soil physicists are perhaps unfamiliar with methods of procedure other than by the method of least squares, which is so laborious as to limit its application, the method which was used to derive these formulæ is explained in detail for two of these, one of which is a simple case and the other much more complicated. The method used is that explained in Engineering Mathematics, C. P. Steinmetz, New York, 1917, pages 209–274, to which reference is also made for an explanation of the properties of different curves.

In the following description, the number of days on which the moisture position was observed is denoted by x and the position of advancing moisture measured in inches above the water surface is denoted by y. The corresponding values of x and y were tabulated and plotted as a curve. It is apparent that the curve in every instance must pass through the origin, for when $x=0$, $y=0$, and the nature of the problem also suggests that the curve be in the form of a parabola. This was found to be true in the majority of cases, but, as will be seen in the formulæ given on a subsequent page, the curve law in some instances changed within the range of the observations.

Curves which are represented by $y=ax^n$ are parabolic or hyperbolic curves passing through the origin. When n is positive, the curve is parabolic. When n is negative, the curve is hyperbolic.

The logarithm of the equation $y=ax^n$ is $\log y=\log a+n \log x$, which is a straight-line formula. If the curve resulting from the plotting of the logarithm of y against the logarithm of x is a straight line, the curve representing the data is a parabola or hyperbola.

The equation for the exponential curve is $y=a\varepsilon^{nx}$, which usually occurs with negative exponent in the form $y=a\varepsilon^{-nx}$, which gives $\log y=\log a-nx \log \varepsilon$. Log y is a linear function of x and plotting log y against x, or log x against y, gives a straight line. Thus plotting log y and log x and x and y against each other permits the form of curve to be recognized. If constant terms exist, the logarithmic line is curved. By trying different constants, the logarithmic line changes in curvature, so that such constants may be found which make the logarithmic line straight.

Logarithmic cross-section paper may be purchased which has both coordinates divided in logarithmic scale and also semilogarithmic cross-section paper having one ordinate so divided. When evaluations of equations having constant terms are to be made, these papers are very convenient, since the curves may be plotted without looking up the logarithms; but since the method described by Steinmetz

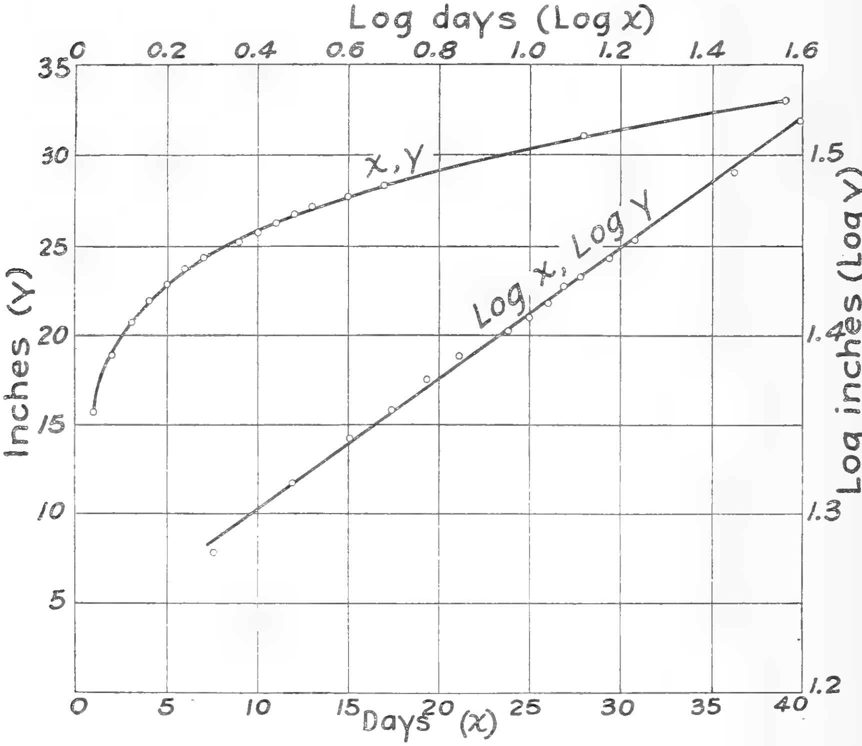

FIG. 8.—Method of developing formula for movement of moisture in flume 43.

requires logarithms to be tabulated in order to calculate the constants, common cross-section paper will usually suffice.

In figure 8 the data representing moisture movement in flume 43 are plotted. The values of log y and log x are also plotted and found to be a straight line, so that log y=log a+n log x and the curve is a parabola. Table 36 gives the data, the logarithms of x and y and the calculated log y as obtained from the formula which was derived.

TABLE 36.—*Flume 43.*

x days.	y inches.	Log x (log days).	Log y (log inches).	1.224 +.186 log x.	y_c* (inches).	Δ
1	15.70	0	1.196	1.224	16.75	+1.05
2	18.95	.301	1.278	1.280	19.05	+0.10
3	20.75	.477	1.317	1.313	20.56	−0.19
4	22.00	.602	1.342	1.336	21.68	−0.32
5	22.82	.699	1.358	1.354	22.59	−0.23
6	23.75	.778	1.376	1.369	23.39	−0.36
7	24.45	.845	1.388	1.381	24.04	−0.41
9	25.25	.954	1.402	1.402	25.24	−0.01
10	25.75	1.000	1.411	1.410	25.70	−0.05
11	26.25	1.041	1.419	1.419	26.25	0.00
12	26.75	1.079	1.427	1.425	26.61	−0.14
13	27.15	1.114	1.434	1.431	26.98	−0.17
15	27.75	1.176	1.443	1.443	27.75	0.00
17	28.37	1.230	1.453	1.453	28.37	0.00
28	31.00	1.447	1.491	1.493	31.12	+0.12
39	33.00	1.591	1.519	1.520	33.11	+0.11
48	34.00	1.681	1.531	1.536	34.36	+0.36
50	34.75	1.699	1.541	1.540	34.68	−0.07

* y_c, distance in inches computed by using the formula derived for flume 43.

The 18 sets of observations are divided into two groups of 9 each. The sum of the first 9 log x and log y are found, together with the second group of 9. These are indicated as Σ9 in the computations. Since the formula log $y=$ log $a+n$ log x applies to all parts of the curve, it is the same for the two groups, subtracting the two groups from each other eliminates log a and dividing the one difference Δ by the other gives the exponent n,

$$n=\frac{\log\ y_2-\log\ y_1}{\log\ x_2-\log\ x_1}$$

The sum of all the values of log x, Σ_{18}, is found and multiplied by n, and the product subtracted from the sum of all the log y, log $a=$ log $y-n$ log x. The difference, Δ, is divided by 18 and the quotient is the log a.

The actual computations for the above case are as follows:

$$\log x\ \Sigma_9=5.657 \qquad \log y\ \Sigma_9=12.068$$
$$\Sigma_9=12.060 \qquad \Sigma_9=13.259$$
$$\Delta=6.403 \qquad \Delta=1.191$$
$$n=\frac{1.191}{6.403}=0.186$$
$$\log x\ \Sigma_{18}=17.716 \qquad \log y\ \Sigma_{18}=25.327$$
$$17.716\times 0.186= \qquad 3.295$$
$$\Delta= \qquad 22.032$$
$$22.032\div 18=1.224=\log a$$
$$a=16.75$$
$$y=16.75x^{0.186}$$

TABLE 37.—*Flume 31.*

x (days)	y (inches)	log x (log days)	log y (log inches)	y_1	$y_2=y_1-y$	log y_2	$y_2+5.5$	log $(y_2+5.5)$	9.031 +1.06 log x	y_c* = 21.39 $x^{0.4}$ − (0.43 $x^{1.06}$ − 5.5)	Δ
1	20.00	0	1.301	20.00	0	0					
2	28.45	.301	1.454	28.21	−.24	$\bar{9}$.380					
3	33.75	.477	1.528	33.96	.21	$\bar{9}$.322					
4	37.90	.602	1.579	37.24	−.66	$\bar{9}$.820					
5	41.20	.699	1.615	40.71	.51	$\bar{9}$.708					
6	44.60	.778	1.649	43.80	−.40	$\bar{9}$.602					
7	47.00	.845	1.672	46.59	−.41	$\bar{9}$.613					
8	49.15	.903	1.692	49.14	−.01	0					
9	51.30	.954	1.710	51.51	.21	$\bar{9}$.322					
10	53.30	1.000	1.727	53.73	.43	$\bar{9}$.633					
11	55.60	1.041	1.748	55.81	.21	$\bar{9}$.322					
12	57.50	1.079	1.750	57.79	.29	$\bar{9}$.462					
13	59.05	1.114	1.771	59.67	.62	$\bar{9}$.792	6.12	.793	.812	58.68	−0.37
14	60.03	1.146	1.778	61.47	1.44	.158	6.94	.841	.846	59.96	−0.07
15	61.40	1.176	1.788	63.19	1.79	.253	7.29	.863	.878	61.14	−0.26
16	62.35	1.204	1.794	64.84	2.49	.396	7.99	.903	.907	62.37	+0.02
17	63.25	1.230	1.801	66.43	3.18	5.07	8.68	.939	.935	63.32	+0.07
18	64.15	1.255	1.807	67.97	3.82	.582	9.32	.969	.962	64.31	+0.16
19	65.20	1.279	1.814	69.46	4.26	.629	9.76	.989	.987	65.26	+0.05
20	66.15	1.301	1.821	70.89	4.74	.675	10.24	1.010	1.010	66.15	0.00
21	67.10	1.322	1.827	72.29	5.19	.715	10.69	1.029	1.033	67.00	−0.10
22	67.90	1.342	1.832	73.65	5.75	.760	11.25	1.053	1.053	67.85	−0.05
24	69.35	1.380	1.841	76.26	6.91	.840	12.41	1.094	1.094	69.34	−0.01
25	70.30	1.398	1.847	77.51	7.21	.858	12.71	1.104	1.114	70.01	−0.29
27	71.45	1.431	1.854	79.94	8.49	.929	13.99	1.146	1.148	71.38	−0.07
29	72.60	1.462	1.861	82.25	9.65	.985	15.15	1.180	1.181	72.58	−0.02
30	73.02	1.477	1.863	83.38	10.36	1.015	15.86	1.200	1.196	73.18	+0.16
32	74.35	1.505	1.871	85.56	11.21	1.050	16.71	1.223	1.226	74.23	−0.12
35	75.80	1.544	1.880	88.68	12.88	1.110	18.38	1.264	1.267	75.69	−0.11
38	77.25	1.580	1.888	91.64	14.39	1.158	19.89	1.299	1.306	76.91	−0.34
43	78.90	1.633	1.897	96.29	17.39	1.240	22.89	1.360	1.363	78.72	−0.18
46	79.95	1.663	1.903	98.93	18.98	1.278	24.48	1.389	1.394	79.66	−0.29
49	80.00	1.690	1.906	101.45	20.85	1.319	26.35	1.421	1.423	80.48	−0.12
55	81.90	1.740	1.913	106.25	24.35	1.387	29.85	1.475	1.475	81.90	0.00

* y_c, distances in inches computed by using the formula derived for flume 31.

In table 37 are given the data obtained from flume 31, the logarithms of x and y being tabulated. Figure 9 shows that the logarithmic curves between log x, log y, and x and y are not straight, so that the curve is not a simple parabola or exponential curve. The curve between log x and log y is straight up to 12 days. Thus the curve is a simple parabola for values of x less than 12. The 12 sets of observations are divided into two groups of six each and the formula derived as explained for flume No. 42.

$$\log x\ \Sigma_6 = 2.857 \qquad \log y_1 \Sigma_6 = 9.126$$
$$\Sigma_6 = 5.823 \qquad \Sigma_6 = 10.308$$
$$\Delta = 2.966 \qquad \Delta = 1.182$$

$$n = \frac{1.182}{2.966} = 0.40$$

$$\log x\ \Sigma_{12} = 8.680 \qquad \log y_1 \Sigma_{12} = 19.435$$
$$8.680\ xn = \qquad 3.472$$
$$\Delta = 15.962$$

$$15.962 \div 12 = 1.330 = \log a$$
$$\log y_1 = 1.330 + 0.40 \log x$$
$$y_1 = 21.39\ x^{0.4}$$

The values of y_1 are calculated from this formula and tabulated in Table 37.

The differences between y_1 and y are also tabulated as y_2. $y_2 = y_1 - y$.

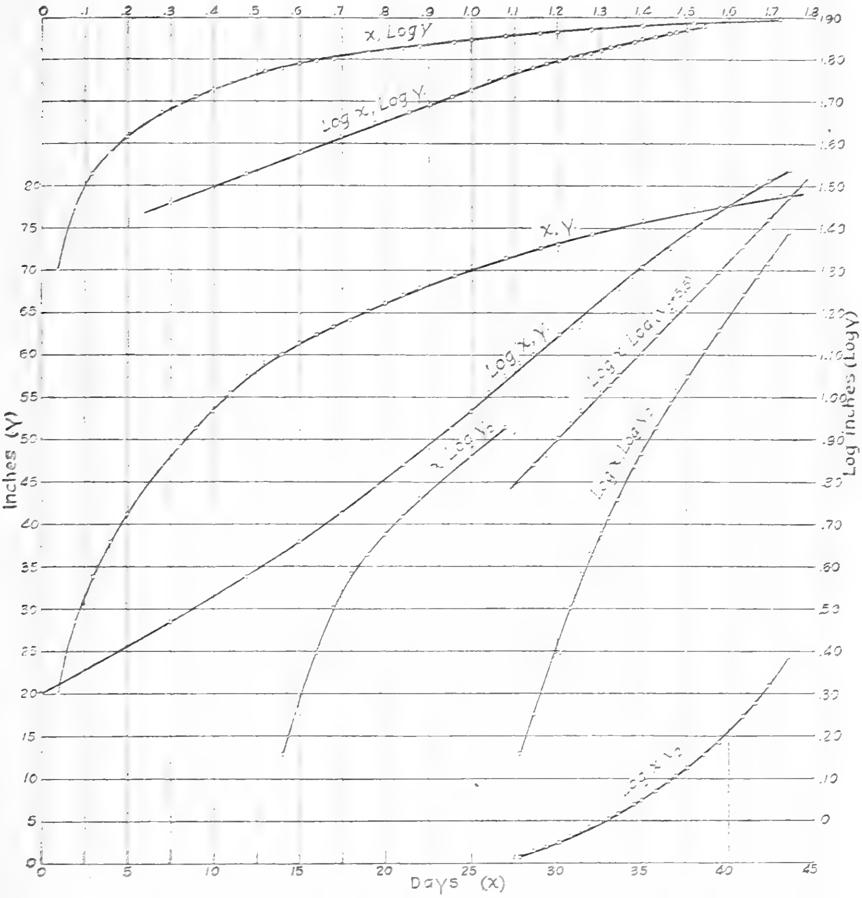

FIG. 9.—Method of developing formulæ for movement of moisture in flume 31.

The values of y_2, log y_2, log y_1 x, log x, and y are plotted against each other as shown in figure 9 A, but none of these curves is a straight line. This suggests the existence of a constant term, and a number of constants were tried until it was found that the curve between log $(y_2+5.5)$ and log x is a straight line. The curve above 12 days or $12x$ then is log $(y_2+5.5)=\log a+n \log x$.

The remaining 22 sets of observations were divided into two groups, and the equation of this parabola was derived as follows:

$$\begin{array}{ll} \log x\ \Sigma_{11}=13.751 & \log\ (y_2+5.5)\Sigma_{11}=10.481 \\ \Sigma_{11}=17.124 & \Sigma_{11}=14.061 \\ \Delta\ =\ 3.374 & \Delta\ =\ 3.579 \\ n\ =\dfrac{3.579}{3.374}=1.06 & \log\ (y_2+5.5)\ \Sigma_{22}=24.542 \\ & 30.875\times1.06=32.666 \\ \log x\ \Sigma_{22}=30.875 & \Delta\ =\ 1.876-10 \end{array}$$

$$1.876-10\div22=9.631-10=\log a$$

$$\log\ (y_2+5.5)=9.631-10+1.06\ \log x$$

$$y_2=0.43\ x^{1.06}-5.5$$

$$\text{Since } y_2=y_1-y,\ y=y_1-y_2$$

$$\text{then } y=21.39\ x^{0.4}-(0.43x^{1.06}-5.5)$$

The values calculated from this equation are tabulated and the differences from the values of y as obtained in the experiment are noted.

When the curve resulting from the plotting x or y against log x or log y is straight, the exponential curve is derived in the same manner as for a parabola. The data are divided into two groups and the value of n and log a found.

$\log y=\log a-nx \log \varepsilon$ represents the equation for both groups, so that log a can be eliminated by subtracting one from the other.

$$n=\frac{\log y_1-\log y_2}{\log \varepsilon\ (\log x_2-\log x_1)}\ \text{in which } \log \varepsilon=0.4343$$

$$\log a=\log y-nx \log \varepsilon$$

In several cases it was found that for high values of x and y the curves were straight lines and the equations for these straight lines found.

Subtracting the values of y_1 in the equation $y_1=mx+b$ from the y values of the data gave values of y_2.

The log y_2 plotted against x gave straight lines, so that the curve for these low values of x and y were exponential curves which were derived as explained above.

The formulæ for the curves representing moisture movement in the flumes held at different angles when filled with Riverside heavy decomposed granite loam (Placentia loam) were as follows:

Flume No. 42 (45° up):

$$y=33.7+0.12x-(18.5\varepsilon^{-0.2x})$$

Flume No. 32 (15° down):

$$y=21.44x^{0.59}-(0.026x^{1.92}-11)$$

Flume No. 34 (30° down):

$$y=22.24x^{0.62}$$

Flume No. 39 (15° up):

$$y=18.36x^{0.28}$$

Flume No. 31 (horizontal):

$$y=21.39x^{0.4}-(0.43x^{1.06}-5.5)$$

Flume No. 43—(vertical up):

$$y=16.75x^{0.19}$$

The following equations were found for other flumes and soils:

Flume No. 33 (15° down) Riverside heavy decomposed granite loam (Placentia loam) Riverside, Calif.

$$y=5.1x+21.-(18.25\varepsilon^{-0.85})$$

Flume No. 61 (45° up) Dublin clay loam, near Whittier, Calif.:

$$y=0.21x+23.7-(15.5\varepsilon^{-0.19}x)$$

Flume No. 51 (horizontal) Dublin clay loam, near Whittier, Calif.:

$$y=11.23x^{0.37}$$

Flume No. 59 (15° up) Dublin clay loam, near Whittier, Calif.:

$$y=15.21x^{0.23}$$

Flume No. 40 (15° up) Riverside heavy decomposed granite loam (Placentia loam) Riverside, Calif.:

$$y=20.53x^{0.31}.$$

Flume No. 30 (horizontal) Riverside heavy decomposed granite loam (Placentia loam) Riverside, Calif.:

$$y=20.89x^{0.47}$$

Flume No. 35 (30° down) Riverside heavy decomposed granite loam (Placentia loam), Riverside, Calif. (for values of x greater than 8, curve is straight line):

$$y=7.3x+12$$

These equations could be used to determine the position of the moisture at some time beyond the range of observation of the experiment if it is assumed that the curve law does not change for higher values of x.

Dr. R. H. Loughridge, in the Report of the College of Agriculture of the University of California for the years 1892, 1893, and part of 1894, pages 91 to 100, gives the observed position of moisture in a column of Ventura County tilled soil (silt loam). These observations extended for a period of 195 days, which is one of the longest periods that has been reported in literature. The formula $y=13.9x^{0.24}$ represents the movement of this moisture and there is no change in the curve throughout the period of observation. Values of y calculated from this formula agree with sufficient accuracy with the observed values of y.

Dr. Loughridge states that the limit of moisture movement was reached at the end of 195 days at 50 inches. It is interesting to note that the position of the moisture at the end of one year as calculated from the formula would be 56.2 inches; at 390 days, twice the time of observation, 57 inches: two years at 66.2 inches; and three years, 72.9 inches, or only 22 inches above what it was at the end of 195 days.

OPEN VERSUS COVERED FLUMES.

The results obtained from the covered flumes are very similar to those obtained from the flumes open on top to evaporation. With one or two exceptions the results with the covered flumes do not differ materially from what could have been foreseen from the results with the open flumes. The essential difference is one of degree, as would have been expected. One striking exception is the fact that in every instance of the 25 or 30 experiments the open flume has the more rapid rate of movement of the moisture for the first one to five weeks of the experiment. the difference in time depending upon the character of the soil. The heavier the soil and the longer the open flume maintained the more rapid rate of movement of the moisture. The more rapid rate of movement is maintained irrespective of evaporation. This fact will be more clearly seen from the data submitted below. There is, as would be expected, a small difference in the relative percentages of moisture contained in two flumes, and especially is this difference noticeable in the upper layers of soil.

Inasmuch as the results with the covered flumes differ only in degree from those of the open flumes, it is not deemed that the submission of all the data and its discussion would add materially to the value of this report. For that reason there will be discussed only one covered flume in its relation to its comparable open flume. The two flumes that will be presented in detail are the horizontal flumes 70 and 71 containing the soil from Upland. This is a gravel and sand soil containing but little clay. The selection of this particular soil for presentation is merely for convenience, as the results obtained by its use are similar to the results obtained from other soils: figure 3 (p. 23) shows the curves representing the movement of moisture in these two flumes.

Table 38 gives the total movement of moisture in these two flumes at the end of various periods of time. From this table it will be observed that flume 70, which is open to evaporation, has the more rapid rate of movement of the moisture up until the fifth day. After the fifth day flume 71, or the covered one, has a more extended movement of the moisture and upon the thirtieth day this difference is about 9 per cent in favor of the open flume. The rate of movement of the moisture in the closed flume is more uniform throughout the 30 days than that in the open flume. The facts just stated would appear to be contrary to what might have been forecast, for the reason that evaporation from the open flume would deprive that flume of some of the water furnished by the wick. In the closed flume practically all of the water furnished by the wick would be available for the capillary action of the soil. These results would indicate first that in the closed flume the soil in the flume proper could not use all of the water that the wick was capable of furnishing. This would indicate a friction factor caused either from partially confined air or otherwise that would not appear to occur in the open flume. It is found in the open flume that either from evaporation or from a more ready circulation of the air the capillary action of the soil within the flume was stimulated or that the friction was reduced. From observations made in connection with other experiments it seems to the writer that the fact of more rapid rate of movement in the open flume at the beginning of the experiment is due to both of these factors. It is known that "trapped" air has an effect upon capillary action and that evaporation would stimulate the circulation of the air.

TABLE 38.—*Movement of moisture at various times, in inches.*

Number of days.	Flume.	
	70	71
	Inches.	*Inches.*
1	23.10	21.30
3		
5	41.70	41.30
10	54.60	54.80
15	64.00	65.50
20	70.15	73.70
30	80.05	87.10

TABLE 39.—*Quantity of water used at various times, in liters, and in percentages of total used in 30 days.*

Number of days.	Flume.			
	70	71	70	71
	Liters.	*Liters.*	*Per cent.*	*Per cent.*
1	6	6	18	21
3				
5	12	12	37	42
10	17	17	54	59
15	21	21	64	72
20	26	24	79	83
30	33	29	100	100

Table 39 shows that a relatively greater quantity of water was used by the closed flume during the forepart of the experiment than was used by the open flume. This is a condition which would be anticipated, as evaporation deprives the open flume of part of the water furnished by the wick. The table shows very clearly that the covered flume does not tax the wick to its capacity in furnishing water from the tank to the flume proper.

Table 40 gives the quantity of water required to move moisture in the flume an average distance of 1 inch for different periods of time. This table does not show effects other than would have been anticipated. It is observed that there is a greater use of water on the thirtieth day in flume 71 than during the fore part of the experiment. This can be accounted for in two ways: First, all evaporation could not be eliminated without liability of trapping the air within the flume. Second, there is, as has been shown previously, an increase in the percentage of moisture contained in different portions of the flume with the age of the experiment.

Table 41 gives the use of water by these flumes in equivalent depth over an area equal to the cross section of the flumes.

TABLE 40.—*Water required at various times to advance moisture an average distance of 1 inch.*

Number of days.	Flume.	
	70	71
	c. c.	*c. c.*
1	259	281
5	288	291
10	311	310
15	328	321
20	371	326
30	412	333

TABLE 41.—*Water removed from tanks at various times, in depth.*

Number of days.	Flume.	
	70	71
	Inches.	*Inches.*
1	3.66	3.66
5	7.32	7.32
10	10.37	10.37
15	12.81	12.81
20	15.86	14.64
30	20.13	17.69

It is found that flume 70 used the equivalent of 20.13 inches of water in 30 days, while the covered flume (71) used the equivalent of 17.69 inches or about 12½ per cent less than the open flume. These figures show that for the last ten days of the experiment the open flume used 4.27 inches and the closed flume 3.05 inches or a little over 25 per cent less water than the open flume. These last figures would represent the effect of evaporation. In other words, during the last ten days of the experiment evaporation from the flume took care of at least 25 per cent of the water furnished by the wick.

EFFECT OF TEMPERATURE ON SOIL-MOISTURE CONDITIONS.

As has been stated previously, a temperature at and below the freezing point appears to have influenced to a marked extent the distribution of moisture within the flumes. Some few soil samples taken from the flumes during the winter of 1916–17 gave results contrary to what was to be expected. In the sampling of the flumes, two samples were taken from each point of sample. The soil from the top 5 inches was placed in one bottle and the soil from the bottom 5 inches in a second bottle and the moisture determined for each separately. There are two basic reasons why the percentage of moisture in the top samples should be less than that in the samples from the bottom 5 inches. First, the sample from the upper 5 inches of soil is farther away from the water and gravity would tend to hold the moisture in the lower layer. Secondly, evaporation from the surface would tend to further reduce the moisture at and near the surface. Thus the laws of physics would indicate a lower percentage of moisture toward the top of the flume than near the bottom. There were, however, several instances where this relationship was interchanged, and more especially was this noticeable during the winter of 1916–17. When this interchanged relationship in the distribution of moisture was observed so frequently during the spring of 1917 as to almost preclude the probability of error from sampling, it seems evident that the unlooked-for distribution of moisture was the result of some natural condition. It soon became apparent that the top part of the flumes showed the greater percentage of moisture during only that time of the year when the air temperature was or recently had been below 30°. In looking back over the results of the preceding winter, this same condition was found. When these facts became evident it was so late in the season that there was no opportunity to prove the matter beyond a question of doubt. For this reason a few of the samples, with percentage of moisture and air temperature, are given in Table 42 for what they may be worth.

TABLE 42.—*Soil-moisture distribution and air temperature.*

Date.	Distance.	Flume.	Percentage of moisture.		Temperature for week preceding.	
			Top 5 inches.	Bottom 5 inches.	Maximum.	Minimum.
	Inches.		*Per cent.*	*Per cent.*		
Mar. 5, 1917	21	90	31.53	29.32	70°	27°
	38		27.44	36.30		
	62		26.33	25.66		
	92		23.37	23.67		
	44	95	29.11	26.83	70°	27°
	128		27.78	26.64		
	201		41.13	28.46		
Mar. 16, 1917	32	92	28.75	30.44	77°	26°
	68		26.45	26.38		
	104		25.75	25.45		
	140		24.30	24.60		
	190		17.83	19.32		
Apr. 21, 1917	32	101	28.31	29.90	82°	32°
	72		20.61	22.00		
	56		25.13	25.47		

At a distance of 82 inches in flume 93 there was taken on March 20 a set of samples dividing the boring into four samples, each containing 2½ inches of soil in depth, and the following results obtained:

In the top sample, 28.96 per cent.

In the second sample, 27.56 per cent.

In the bottom sample, 26.60 per cent.

In addition to the samples given above there are several others showing similar results. There are some samples taken at the same time in the same flume that gave the natural distribution of moisture and the interchanged distribution. In these cases there was not as great a difference in the relative percentages of moisture at the top and bottom as where all samples showed the interchanged relation.

In the samples given above, it is noticed that this interchanged relation of the distribution of the moisture occurs in both the open and covered flumes. This same fact is true of all of the other work, except that the covered flumes seem to require a little lower temperature of the air to cause this result than do the open flumes. It will be noticed in Table 42 that with a relatively low percentage of moisture an interchange of the natural distribution of the moisture did not occur. It is probable that if such a distribution should occur, a temperature lower than 26° F. would be required. As shown in this table, for flume 101, with the minimum temperature of 32°, the upper part of the soil still contained a little less moisture than the bottom part of the soil. By comparing results shown for flume 101 with other samples taken with higher minimum temperatures, it is evident that a slight difference occurred in the normal distribution of the moisture in the samples.

Before a definite conclusion can be drawn, additional experiments will have to be made.

THE CAPILLARY SIPHON.

The definitions of capillarity and of capillary moisture used in so many of the old textbooks would lead one to conclude that free water would not be developed as a result of capillarity. For instance, the old illustration of the towel and the basin of water was used to combat the idea of free water as a result of capillarity. No reference to the probable fallacy of the old doctrine has been stated. In fact, all reference to the relation of gravity and capillary action, except as contained in the old original definition, has been in the most general terms. The prevalent method of disposing of the question is to say that capillary action is influenced by gravity. (1) There appears to be no statement as to any quantitative relation.

One of the very first sets of experiments tried at Riverside in the fall of 1915 included flumes inclined at angles of 15° and 30°, and one at 45°. The first of these had an ultimate total length of 20 feet and the last two had lengths of 10 feet each. The moisture in the flume inclined downward at 45° had reached the end of the flume in 18 days, and in the one inclined downward at 30°, the moisture had reached the end of the flume in 21 days. Three or four days after the moisture had reached the end of these flumes, free water was observed dripping from the ends of both. In about a week after the moisture had reached the lower end of the flume inclined downward at an angle of 15° free water commenced dripping from the lower end. The water continued to drip from the ends of all three of these flumes for at least two weeks, or until the flumes were dismantled. It must be kept in mind that this water was raised from the tank a vertical distance of 4 inches by capillarity and against gravity. It was then transmitted down the flumes by means of the same force and in a direction with gravity. The moisture left the soil column at the lower end of the flume as free water, dropping to the ground. At no point in the entire length of the soil column, with the possible exception of the extreme lower end of the flume, was the percentage of moisture in the soil as great as that of capillary saturation, as measured by the general methods for determining this percentage. This, then, is in effect transferring water from a body of free water by capillarity and delivering it again as free water.

To supplement the results from the flumes and to test the further possibility of creating a capillary siphon, a special piece of apparatus shown in figure 10 was set up.

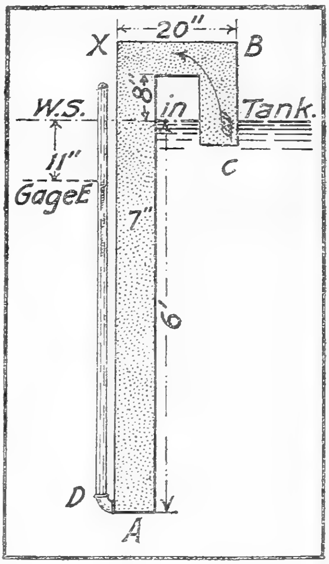

FIG. 10.—The soil column as a capillary siphon.

A–B in figure 10 is a galvanized-iron tube 7 by 7 inches in area and made in the shape shown. This box is water-tight and air-tight, except along the top *X–B*, at the bottom of the short arm at *C*, and at a point *D* at the bottom of the long arm. This tube stands vertical and rests on *A*. The top along the line *X–B* is open to the air. The lower end of the short arm at C has soldered over it a fine-meshed wire gauze. *D* is a ⅝-inch ell soldered into the lower end of the long arm; the top of the ell is fitted with a water-gauge connection. Into the top of this ell is fitted a gauge glass *X–D*, on the outside of the tank or tube. The tube is packed with soil as indicated and the soil is exposed to the air along the line *X–B*. The short arm of the tube extends down into a tank of water represented by water line in tank.

It is observed from figure 10 that the high-water line in the tank is 8 inches below the bottom of the horizontal part of the tube. This 8 inches is then the distance the water must be raised from the tank before it can move horizontally. It must then move horizontally an average distance of 12 inches before it can move downward.

The detailed measurements will not be given, but after 60 days the water in the gauge glass on the outside of the flume showed water up to a point within 11 inches of the surface of the water in the tank; that is, after 60 days that part of the tube below the point designated "Gage E" in gauge glass was completely saturated. After the sixtieth day, the rate at which the water rose in the gauge glass was very slow, and upon the seventieth the experiment was terminated.

This experiment, as did the previous ones cited, gave free water as a result of capillary action.

Three additional experiments were run with the same tube, but containing soils of a different type. In each case the same result was obtained, except that they were terminated sooner and for that reason the water did not rise so high in the glass.

Finally, it may be stated that in every flume, covered and open, that was inclined downward at an angle from 15° to 45° free water was developed when the experiment was run for a sufficient time. In only 3 or 4 instances out of the 20 or more flumes so inclined were the experiments terminated before free water was dripping from the lower ends of the flumes.

Several tests were made of the amount of water taken up from the tanks and delivered again at the lower end of the flumes as free water. One of these tests will be given.

The flume selected is No. 95, containing the lava soil from Idaho. This flume was covered, inclined downward from the horizontal at an angle of 30°, and was 15 feet in length. The records show that the flume commenced dripping water at the lower end on February 25, 1917. Commencing with March 1, the quantity of water lost from the tank by the wick was 18 liters. During this same period there was caught at the lower end of the flume 8.78 liters, or approximately 50 per cent of the quantity taken from the tank. The water was caught in a can as it dripped from the flume.

It has been suggested that a true siphon might have been formed as a result of "soil puddling" or other natural mechanical means. It did not occur in many cases and it is doubtful if it occurred at all. It is found, for instance, that with the use of clean, coarse building sand, devoid of clay or other fine material, the same result is obtained. However, to test this point further, a system of ventilation within the wick was installed.

Ventilating pads were made out of ordinary window-screen wire. From six to eight thicknesses of wire were rolled into a very small diameter and then flattened out. This made a pad of wire about

$2\frac{1}{2}$ inches in width and about three-eighths of an inch in thickness. The wire, when placed within the soil, kept the soil particles apart throughout most of the spaces occupied by the pad. Four of these wire pads were inserted vertically within the wick, extending from within about one-half inch of the water in the tank up through the wick of the flume to the air above. These pads were placed in the corners of the wick and about 1 inch from any side. The flume and wick were then packed with soil and the experiments started. With the flume inclined downward at an angle of 30°, and with the light sandy Idaho soil, water dripped from the end of the flumes in about four days and continued to drip until the experiment was discontinued. This experiment was repeated, and in addition to the vertical ventilating pads, two other pads were placed, one diagonally across the wick and one in a horizontal position. The ends of these pads butted against the vertical pads and were placed about 1 inch above the surface of the water of the tank.

This flume gave the same results as the other flume, but a little less water was taken from the tank in the case of the ventilated wicks than in the wicks not ventilated. However, free water dripped from the lower end of all of these flumes. In the wick having the vertical and horizontal pad ventilators (so called) there was no unventilated space within the wick at a greater distance than $1\frac{1}{2}$ inches from a ventilator.

In several of the flumes inclined downward, various other means of ventilating the wick were tried and in each case free water was still given off at the lower end of the flume.

A flume inclined downward at an angle of 15° and 20 feet long was filled with clear Santa Ana River sand. This sand contained practically no fine material and only traces of organic matter. Yet this flume, like the others described above, gave free water at the lower end of the flume, and within a week from the time the experiment was started.

It would seem, therefore, from the evidence of the ventilated wicks and flumes filled with types of soil from very coarse sand to fine clay and all giving off free water, that the capillary siphon, as above styled, is perfectly established.

It would also seem that capillary siphons occurring in nature might not be uncommon and that such siphons, first by capillarity alone, and later assisted by gravity, might cause the swamping of lands. Such a condition might arise if there were a stratum of soil of rather high capillary power and a rather impervious subsoil; if the upper end of such a soil arrangement were in contact with a body of water and the water did not have to be lifted too far by capillarity, and from that point the soil and subsoil had a slope downward at an angle at least as great as 15°, then it would have the condition of the flumes above described. If, now, there were a sudden change in the slope of the ground toward the horizontal, or if the more loamy soil verged into a denser soil, free water might be developed at this point as the result of capillary action.

The capillary siphon might develop, also, in an earthen reservoir dam with a puddle or concrete core wall extending only to the flow line or slightly above it, and under certain conditions produce saturation in the lower side of the dam.

That a capillary siphon as above described is in accord with physical laws and was not the result of mechanical defects or error in manipulation is readily proven. Briggs (13) and Widtsoe and McLaughlin (19) have shown that the quantity of water retained by a soil column against gravity depends upon its length. Also that a column 1 foot in length will hold at all points a greater percentage of water than a column 2 feet in length. Hence, as the length of the inclined flume is greater, the percentage of moisture held against gravity will be smaller. It would follow, therefore, that beyond a certain length of the inclined part of the flume, not all of the water furnished by the wick could be retained against gravity by the inclined part of the flume.

It has been shown in this report that the distribution of moisture in vertical soil columns does not decrease uniformly with height above water. It has been indicated also that the greatest percentage of moisture in the vertical column may not be at the immediate water surface. From moisture analyses made of samples from vertical flumes, noted in this report, and from a great many other special experiments, the writer will say that the greatest percentage of moisture in a vertical soil column with its lower end in water may be and frequently is at an appreciable distance above the water. From these data and as the result of tests by the writer and others, it can be said that a vertical soil column can take up by capillarity from a body of free water more water than it can hold against gravity, if the free water be removed from the bottom of the soil column: that is, if the vertical tube is filled with soil and the lower end placed in a vessel of water and allowed to stand for a month or longer and the water is then removed from the tank, a part of the moisture in the soil column will drain out. To repeat—a vertical soil column will take up by capillarity from a body of water more moisture than it can retain when the source of the water is removed. In view of the above statements and the recorded experiments, it appears that capillary siphons may occur in nature, as the result of physical laws.

CAPILLARY MOVEMENT OF MOISTURE FROM A WET TO A DRY SOIL.

As has been stated previously, the movement of moisture by capillarity is much slower and not so extensive in the absence of free water as it is in the presence of free water. When a wet soil and a dry soil are in contact, gravity exerts an appreciable influence in the capillary movement of moisture.

The experimental work so far done at Riverside does not warrant more than a few general statements. To give some idea of the nature of this work a few experimental results will be given.

THE VERTICAL BOXES.

The soil boxes were placed in vertical and horizontal positions only. In the vertical boxes the wet soil was placed in some cases on top, in others at the bottom, and in others the wet soil was placed in the middle section and dry soils at both ends.

Nearly all boxes were 6 feet in length and the wet soil occupied one half this length and the dry soil the other half.

MOVEMENT OF MOISTURE UPWARD.

In table 43 are given data of a few of the boxes in which the soil moistened to the percentages shown were placed at the lower ends of

TABLE 43.—*Movement of moisture upward in the boxes.*

Days.	Riverside soil, initial percentage.		Idaho lava soil, initial percentage.			Whittier soil, initial percentage.	
	20 per cent.	10 per cent.	14 per cent.	20 per cent.	25 per cent.	40 per cent.	30 per cent.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	1.12			1.50			
2	2.25				1.00		
3	3.00	1.25	1.25				
4	3.37			2.25			
5	4.00						
6	4.50		1.83				
7	4.82	2.00					
8	5.00						
9	5.37			3.25	4.50		
11		2.25					
12			2.75				
14	7.00				6.50		
16				4.50			
23	8.37	4.37	3.25		7.75		
26						1.70	1.00
37	10.75		3.50	6.83			1.75
40					10.50		
49					11.00		
56	12.75						
71		6.50					
86					14.25		

the boxes and air-dried soils at the upper ends. The table shows that the box containing the Riverside soil, with the lower half 20 per cent of moisture, the movement of the moisture up into the dry soil was about one-fourth as great in 4 days as it was in 56 days. In the box of Riverside soil, containing 10 per cent moisture in the wet pack, the movement of moisture into the dry soil the first 3 days was about one-fifth as great as in 71 days.

The other data in the table show the relatively rapid rate of moisture movement the first few days and the slowing down of the rate of movement with the lapse of time.

These results in connection with previous data for the flumes indicate that the larger part of capillary distribution of the water occurs while water is being applied and in the next two or three days thereafter.

The last two columns of the table, which give data for the heavy Whittier soil, show the very slow and limited capillary movement of moisture in this class of soils.

In the three boxes containing the Idaho lava-ash soil with relatively great capillary power, the movement of moisture up into the dry soil did not extend very far. In the box the wet pack of which contained 25 per cent of moisture the upward movement in 86 days was only 14.25 inches. The field capacity of this soil is from 20 to 25 per cent or a little less than the percentage of moisture in the box just considered.

In the box the wet pack of which contained 14 per cent of moisture the movement of the moisture upward was only 3½ inches in 37 days.

If the data in Table 43 were plotted as were the data for the flumes the resulting line would have a parabolic form.

MOVEMENT OF MOISTURE DOWNWARD.

Table 44 is arranged to show the distance the moisture moved downward in the boxes after various periods of time, the moist soils being placed above the air-dried soils. The table shows about the same conditions as did the previous table, except that the rate and extent of movement of the moisture downward are considerably greater than with the wet soils below the dry. The rate of movement downward is in proportion to the initial percentage of moisture contained in the wet soil.

In the Riverside soil containing 15 per cent of moisture, or about the field capacity, the extent of movement of the moisture at the end of the fourth day is approximately one-half the distance moved in 36 days. In the Idaho soil containing 20 per cent of moisture in the wet pack the moisture had moved in 36 days only about two and one-half times as far as it had at the end of 4 days. In the heavy Whittier soil the movement of the moisture even with a moisture content in the wet pack equal to or greater than the field capacity is very slow and does not move to any great distance in 30 days. The data of this table, if plotted, as were the other data, would give a curve resembling a parabola.

TABLE 44.—*Movement of moisture downward from wet soil.*

Days.	Riverside soil, initial percentage.		Idaho lava soil, initial percentage.			Whittier soil, initial percentage.	
	20 per cent.	15 per cent.	14 per cent.	20 per cent.	25 per cent.	41 per cent.	30 per cent.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	4.50	4.00	0.75	2.00	3.00	....	....
2	....	5.75	....	....	5.25	....	....
3	7.50	6.37	....	....	....	....	....
4	....	7.00	....	4.75	....	....	....
5	....	....	1.75	5.00	....	....	....
7	....	....	....	....	9.00	....	....
8	11.75	8.50	....	....	....	....	....
9	....	....	4.00	8.00	....	....	....
13	14.00	9.50	....	....	12.00	....	....
16	15.75	10.75	4.50	8.50	....	....	....
22	17.25	11.25	....	....	15.25	....	....
27	....	12.00	....	....	....	....	....
31	21.50	....	....	....	16.25	2.25	2.00
36	....	14.25	....	11.50	17.25	....	....
41	....	15.00	....	....	....	....	....
43	25.50	....	....	....	....	....	....
49	....	16.25	....	12.75	....	....	....
71	....	....	....	....	21.50	....	....
76	....	....	....	....	22.25	....	....

COMPARISON OF CAPILLARY MOVEMENT OF MOISTURE UPWARD AND DOWNWARD FROM A BODY OF WET SOIL.

A series of experiments were outlined to determine the relative extent and rate of movement of moisture upward and downward from a body of soil containing a known percentage of moisture. In this experiment a section in the middle of the box was filled with wet soil and air-dried soil was packed at both ends. The box was then placed vertically. In this experiment the capillary movement occurred with gravity downward and in opposition to gravity. There was a secondary factor which must be considered, and that is the gradual concentration of moisture in a wet soil at the lower end of a vertical column due to gravity. That is, while the middle part of the flume was filled with a soil containing a uniform percentage of moisture it would be found after a few days, depending upon the degree of wetness of the soil, that there was a greater percentage of moisture near the bottom than near the top of the wet soil column. The more nearly the soil was wetted to the point of capillary saturation the greater would be the difference in percentage of moisture near the bottom and near the top.

Table 45 shows the upward and downward movement of moisture in two of the boxes.

The box containing the Idaho soil was 8 feet long and the middle 32 inches was packed with wet soil. There was an equal length of air-dry soil at each end.

The box containing the Riverside soil was 8 feet long and the middle 4 feet was packed with wet soil.

TABLE 45.—*Movement of moisture upward and downward, from soils containing an initial moisture content of 15 per cent.*

Time in days.	Idaho soil.			Riverside soil.		
	Distance moved.		Relation of up to down.	Distance moved.		Relation of up to down.
	Up.	Down.		Up.	Down.	
	Inches.	*Inches.*	*Per cent.*	*Inches.*	*Inches.*	*Per cent.*
2	1.50			2.25	3.50	64
4	1.50	2.25	67			
5				2.62	7.25	36
6	2.30	3.20	73	2.88	7.75	37
10				3.75	10.00	37
13	3.00	4.50	67			
17				5.75	13.00	44
23	4.12	5.50	75			
31	4.50	6.75	67			
36	4.80	7.00	68	6.50	18.25	35
43				6.75	19.00	36
52	5.37	8.37	64			
71	6.00	9.12	66			
76	6.25	9.24	67			

Table 45 shows by percentage the relation of the upward movement of the moisture to the downward movement. After the first day or two the relation of the upward movement to the downward movement remains rather constant. The table shows the relative rapid rate of movement of moisture the first few days and the slower rate with the lapse of time. If the data in Tables 41 and 42 showing the upward and downward movement of moisture in separate flumes are compared, the same relative relation is found as found in Table 45.

The above data indicate the part gravity plays in soil-moisture distribution. Generally speaking, the lighter the soil the less is the upward movement of the moisture as compared with the downward movement. It also appears that the greater the percentage of moisture the greater the downward movement as compared with the upward.

The limited data above presented, when considered with many others in the original records, would lead to the conclusion that under irrigation much moisture may be carried below the root zone of plants, and that moisture once carried below the root zone of plants will probably not be again brought within the root zone in sufficient quantity to be of material benefit to the crop of that season, and hence will be lost to the plant.

THE MOVEMENT OF MOISTURE FROM WET TO DRY SOIL IN HORIZONTAL BOXES.

The capillary movement of soil moisture in a horizontal direction as found in the horizontal boxes is greater in extent than the upward movement in the vertical boxes, but not so great as the downward movement. There are given in Table 46 the results of three tests with the Riverside soil, with 10, 15, and 20 per cent moisture in the wet soil. The table shows, like the preceding ones, that the rate and extent of movement of the moisture varies as the initial percentage of moisture in the wet pack. There is also shown the rapid moisture movement for the first few days and a slowing down of this rate with lapse of time. These data if plotted would also give a curve of a parabolic form. It is surprising to find so great an extent of movement of moisture in a horizontal direction when compared with the downward movements as shown in Table 42. If the difference in movement of moisture in the several boxes as representing the upward, downward, and horizontal can be attributed only to gravity, and this appears to be true, then gravity is a most important factor in the capillary distribution of soil moisture.

TABLE 46.—*Horizontal movement of soil moisture in Riverside soil.*

Time in days.	Initial moisture.		
	10 per cent.	15 per cent.	20 per cent.
	Inches.	*Inches.*	*Inches.*
1	0.75	4.00	5.75
2	1.25	5.50	7.00
3	1.50	6.25	8.25
4	......	......	9.25
5	1.83	7.50	9.75
7	......	......	10.75
10	3.00	9.50	......
12	......	......	13.50
16	5.00	11.00	15.00
19	5.25	......	......
21	......	......	16.25
24	......	13.25	......
29	......	......	17.75
40	5.50	18.25	19.50
46	......	......	23.25
49	......	19.00	......
51	......	......	23.50
54	......	19.25	......

While the experiments above noted are not sufficient in number to warrant any final conclusion, in connection with many others not contained in this report they indicate the probably distribution of moisture.

These data are in accord with results obtained by others (7), (9), (10), (18).

DISTRIBUTION OF MOISTURE IN BOXES CONTAINING WET AND DRY SOIL.

It is interesting to observe the distribution of the moisture throughout the entire length of the soil in the boxes at the termination of the experiments. It is interesting to observe the movement of moisture in quantity from the wet soil into the air-dried soil, and in the vertical boxes to note the relative percentages of moisture moved upward and downward. Table 47 gives the distribution of moisture at the end of the experiment in the soil boxes just previously discussed.

In Table 47 are given the kind of soil and the initial percentage of moisture contained in the wet soil as placed in the boxes at the beginning of the experiment. The percentages of moisture and the distances inclosed between the heavy lines in the body of the table show the original wet area of soil in the boxes and the remaining figures outside of the heavy lines show that part of the original air-dried soil with the corresponding percentages of moisture found at the end of the experiment. For instance, in the first two columns the first two lines indicated by minus 5 inches and minus 2 inches represent that part of the soil column immediately below the original wet soil area. Likewise the distances 34 inches and 40 inches at the bottom of the table represent that part of the original air-dried soil on top of the original wet soil. The other part of the table has a similar arrangement, except that the distances were taken from the bottom of the boxes. Referring to the Riverside soil it is found that the distribution of moisture from the bottom of the box upward is quite uniform until near the upper extremity of the original wet area. At a distance of 47 inches 9.19 per cent of moisture is found, while at 50 inches there is 6.6 per cent of moisture. In corresponding distances at the bottom of the box, represented by 22 inches and 18 inches, respectively, a much less variation in the percentage of moisture is found.

TABLE 47.—*Distribution of moisture by percentage in the soil boxes.*

Idaho soil, initial moisture 20 per cent.		Riverside soil, initial moisture 15 per cent.			
Distance.	Moisture content.	Distance.	Moisture content.	Distance.	Moisture content.
Inches.	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*
−5	9.46	3	5.65	5	4.74
−2	11.31	6	7.08	8	6.90
2	14.09	9	8.25	11	8.05
6	14.46	12	8.61	15	8.81
12	15.05	15	9.09	19	9.04
18	16.00	18	9.42	22	8.75
24	15.44	22	10.79	24.5	11.40
28	15.51	25	10.20	27	12.37
31	15.40	26	10.34	30	11.28
34	....	31	10.60	34	11.50
40	....	34	10.00	38	11.05
....	....	37	9.86	42	11.13
....	....	40	9.38	46	10.45
....	....	44	9.50	50	10.40
....	....	47	9.19	54	9.35
....	....	50	6.60	58	9.48
....	....	58	3.90	62	9.43
....	....	....	....	66	8.92
....	....	....	....	70	8.28
....	....	....	....	74	4.99
....	....	....	....	77	3.28

It would seem from Table 47 that gravity has played its part in conjunction with capillarity in a rather uniform distribution of soil moisture from the wet soil area to the dry soil area. Upon the other hand it is found in taking the moisture percentages that gravity has very materially retarded the upward movement of the soil moisture. It is found, for instance, that the percentage of moisture found immediately below the original wet soil area is almost double the percentage of moisture found immediately above the upper end of the original wet soil area.

If such a condition as this maintains in the field, and there is no reason to believe it does not, then we can expect that capillarity and gravity will tend to a deep penetration of the moisture. The figures in Table 47 and those immediately preceding show conclusively that capillarity and gravity tend to move the soil moisture downward to considerable depths and in about twice the quantity that the moisture moves upward. Add to this factor copious irrigation and it is readily seen how even capillarity can assist and does assist in the waste of irrigation water by deep penetration.

In none of the data presented just above has the original wet soil contained a percentage of moisture differing much from that which would be found in the field immediately following an irrigation.

Sufficient tests have not been made to warrant a final conclusion as to the ultimate importance of the deep penetration of moisture, by capillarity, in conjunction with gravity.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 836

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. **PROFESSIONAL PAPER** **April 27, 1920**

BROOM-CORN EXPERIMENTS AT WOODWARD, OKLAHOMA.

By BENTON E. ROTHGEB, *Assistant Agronomist in Charge of Grain-Sorghum and Broom-Corn Investigations, and* JOHN B. SIEGLINGER, *Assistant Agriculturist, Office of Cereal Investigations.*

CONTENTS.

EXPERIMENTS WITH BROOM CORN.

The experiments[1] with broom corn at the Woodward Field Station were started in 1914. The results of five years of work are now available. While this may be too short a period from which to draw final conclusions, it is thought that the results thus far obtained are worthy of publication. Much interest is shown in the crop at this time and a large number of inquiries are being received for information with regard to varietal adaptation, the best time to sow, and the rate of seeding which will give best results in both yield and quality of brush. The results obtained at Woodward and reported herein

[1] These experiments were conducted in cooperation with the Office of Dry-Land Agriculture of the Bureau of Plant Industry. Mr. E. F. Chilcott, of that office, is superintendent of the station. Credit is hereby given him for his hearty cooperation and assistance in conducting these experiments. The senior writer was in charge of this work at the station during the seasons of 1914 and 1915. The junior writer was appointed assistant agriculturist on October 5, 1915, and conducted the experiments at the station in the seasons of 1916, 1917, and 1918.

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are applicable to a greater or less extent to a large part of the southern Great Plains area.

This bulletin contains (1) a description of the district to which the results apply, (2) a description of the Woodward Field Station and the scope and methods of the experiments there conducted, and (3) the results obtained.

DESCRIPTION OF THE DISTRICT.

The section here described includes the plains of Oklahoma and Kansas, a large portion of Texas, and a small portion of southeastern Colorado and of eastern New Mexico. An outline map of this district is shown in figure 1. It includes the main districts producing the Dwarf broom-corn crop and a few localities where the Standard variety is grown. It contains at present approximately 300,000 acres of broom corn, or about 87 per cent of the entire acreage grown in this country.

FIG. 1.—Outline map of the southern Great Plains region, showing the principal district producing the Dwarf broom-corn crop.

TOPOGRAPHY.

The section just outlined lies between the ninety-eighth meridian on the east and the one hundred and fourth on the west. It extends north to the northern boundary of Kansas and south to the thirtieth parallel in Texas. In general, it consists of broad rolling plains interrupted for the most part chiefly by the shallow valleys of the larger rivers. The altitude ranges from approximately 1,000 feet to 4,500 feet above sea level. The average annual rainfall varies considerably in different parts of the district, ranging from about 15 inches in some parts to 30 or more inches in others.

SOIL.

The soils of the area are naturally variable. Those of the eastern part have been exposed to greater precipitation and have been eroded more than the soils of the western part. The soil types found in this extensive area vary from sand to clay, with the loams predominating in the southern and central parts of the area and silt loam in the northern. All are friable and easy to cultivate as compared with similar types under more humid conditions. They are uniformly sweet or nonacid, and under natural conditions contain from 3 to 6 per cent of organic matter. In general, low yields are due to some climatic factor or factors rather than to a lack of soil fertility.

CLIMATIC CONDITIONS.

The weather data considered herein were recorded at Woodward, Okla., during the period from 1908 to 1918, inclusive. Woodward is located centrally in the district described.

The principal climatic features which influence crop production in this section are (1) a limited annual precipitation of irregular seasonal distribution and a great loss of water due to run-off during torrential summer storms, which are quite common in some localities; (2) a relatively low atmospheric humidity; (3) a very high rate of evaporation during the summer months; (4) a wide daily range of temperature, or hot days followed by cool nights; and (5) a high average wind velocity.

Precipitation.

Precipitation and its distribution are important factors in crop production in the section under discussion. There is usually rainfall enough to grow the crop, but the distribution is not always such as to permit the best use by the crop of the moisture which falls. In such cases the crop yields are very low, and in extreme cases total failure results.

MONTHLY AND ANNUAL PRECIPITATION.

Table I shows the monthly, annual, and mean annual precipitation, in inches, at Woodward, Okla., during the 11-year period from 1908 to 1918, inclusive. The mean annual precipitation at Woodward for this 11-year period was 24 inches, of which amount 16.5 inches fell during the growing season, or from April to September, inclusive.

Table I shows a wide fluctuation in both the monthly and the annual precipitation. In April, 1909, the rainfall was 0.45 inch, and for the same month in 1915 it was 7.08 inches, or a difference of more than 6 inches between these extremes. May, June, July, August, and September each have about the same range of fluctuation as April. In the annual precipitation the extreme range is from 14 inches in 1910 to 39 inches in 1915, almost three times as great.

TABLE I.—*Monthly and annual precipitation at Woodward, Okla., during the 11-year period from 1908 to 1918, inclusive.*

[Data (in inches) furnished by the observer of the United States Weather Bureau at Woodward.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.	Mean.
1908	0.25	1.25	1.10	1.70	3.25	3.76	5.87	1.82	4.30	2.75	1.47	0	27.52	......
1909	.05	.28	.66	.45	4.78	2.45	1.54	.29	4.88	2.95	9.54	.15	28.02	27.77
1910	.46	.22	0	1.97	.53	1.17	1.62	7.65	0	.38	0	.01	14.01	23.18
1911	0	8.09	0	.10	4.13	0	3.54	5.29	.41	.82	.52	2.90	25.80	23.84
1912	.03	2.58	2.37	1.63	1.15	3.02	3.25	2.90	3.44	.50	.06	.07	21.00	23.27
1913	.40	2.44	.54	1.11	2.08	5.31	.99	1.87	4.89	1.05	3.50	2.73	26.91	23.88
1914	.18	.51	.34	2.44	3.53	.60	.92	2.92	.82	1.99	.06	.77	15.08	22.62
1915	1.17	3.44	1.45	7.08	6.47	2.87	3.46	3.90	6.27	2.52	.56	.02	39.21	24.69
1916	1.29	.03	.92	2.01	1.74	1.64	0	1.15	2.22	1.87	.95	.38	24.20	24.64
1917	.43	.22	.34	1.93	1.39	1.89	1.33	7.00	1.90	0	.77	.18	17.38	23.91
1918	1.60	.22	1.85	2.51	4.49	2.11	1.79	.70	1.26	3.54	1.73	3.58	25.38	24.04
Average	.53	1.75	.87	2.08	3.05	3.17	2.21	3.23	2.76	1.67	1.74	.98	24.04	......

DISTRIBUTION OF MONTHLY RAINFALL.

The total annual and seasonal precipitation, which is shown graphically in figure 2, may easily be misleading. This is due to

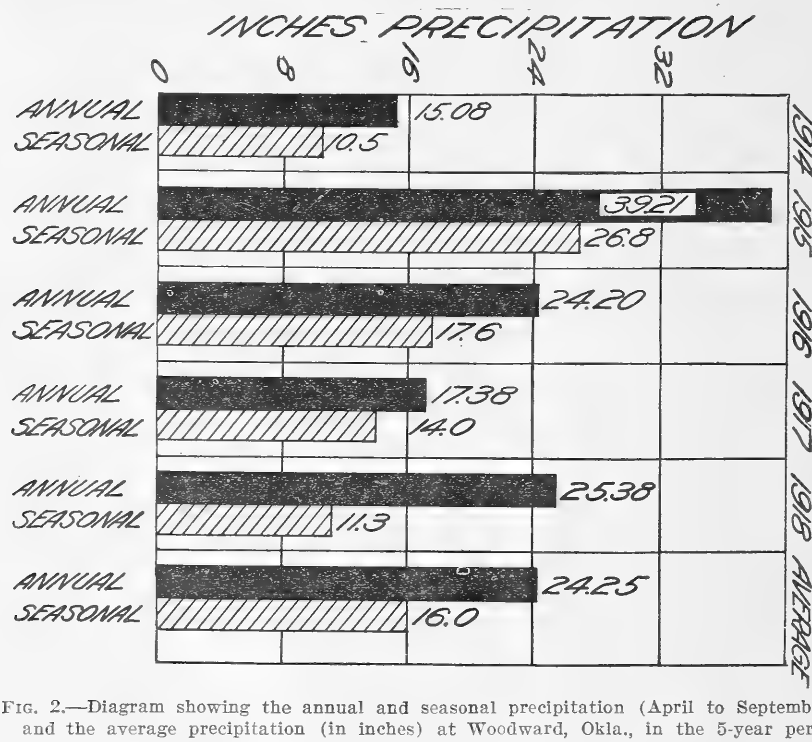

FIG. 2.—Diagram showing the annual and seasonal precipitation (April to September) and the average precipitation (in inches) at Woodward, Okla., in the 5-year period from 1914 to 1918, inclusive.

the irregular distribution of summer rainfall, to the varying quantities deposited by different showers, and to the manner in which it falls. The nature and distribution of the rainfall will be better understood by a careful study of the data in Table II, containing the records of daily precipitation, with monthly totals, throughout the five years from 1914 to 1918, inclusive.

The annual precipitation has been sufficient to produce good broom-corn crops in almost all the years during which these experiments have been conducted, but in several seasons high yields and brush of good quality were not obtained. These poor yields are correlated in some measure with unfavorable distribution of the larger and more important rains.

Distribution may be unfavorable in several ways. Much of the annual rainfall may come within a short period either at the beginning, in the middle, or near the end of the season. The seasonal rainfall may be sufficient in quantity but poorly distributed. Some month may be unusually wet, followed by a long dry spell. Such a condition occurred in 1914, when May was wet and June and July were dry, and again in 1916, when June was wet and July was entirely without precipitation.

Still another condition may occur in which the rainfall is fairly evenly distributed in point of time and about sufficient in quantity and yet be unsuitable for crop production. This is when it occurs in light showers which do not penetrate the soil and are soon evaporated. Showers amounting to half an inch or even more may add little or no water to the soil if followed by high winds and bright sunshine, which cause rapid evaporation. The season of 1918 is a good example of this condition, as may be seen in Table II. While a number of showers fell from June to August, inclusive, only two afforded more than temporary relief to the crop.

TABLE II.—*Daily and monthly precipitation at Woodward, Okla., during the 5-year period from 1914 to 1918, inclusive.*

[Data (in inches) furnished by the observer of the United States Weather Bureau at Woodward. T=trace.]

Date.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1914.												
1					T	T	0.04					
2				0.11	2.00	T	.07	T				
3				.25	.06		.04			T		
4					T		T	T		T		
5		0.04	T	.22	T	T		0.31				0.21
6		T		.14	T	T	T		0.31	1.25		.06
7				T	T	T	.55			.06	0.05	.02
8						T						T
9								.80				T
10					.10							T
11	0.18			.87						.29		T
12		.02							.02			
13		.08							.08	T	T	
14					T				T			
15					.36	0.57						.06
16					.03	.03			.38			T
17		.25		.22	.04		T					T
18		.12		.02	.19		T					T

TABLE II.—*Daily and monthly precipitation at Woodward, Okla., during the 5-year period from 1914 to 1918, inclusive*—Continued.

Date.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1914.												
19			T		T				T			
20					T		T					0.31
21			0.05		0.02				0.03	0.26		
22		T		T		T				T		
23		T		0.20			0.20	0.03		.13		
24			T	.02				T			T	
25											0.01	.08
26				.28	T		.02					
27	T	T		.02	.12			.71				
28					.21		T					.03
29	T		.01	.09	.01	T		.75				
30			T		.13	T		.30				
31			.28		.26			.02				
Total	0.18	0.51	.34	2.44	3.53	0.60	.92	2.92	.82	1.99	.06	.77
1915.												
1		.28			.33	.06		.12				
2			.67			.08	.57	T				
3			.18			T	.82			T		
4		.02	.37			.52	T			.02		
5		T			.09	.02						
6		T	T	1.25	1.16	.22			.06			T
7				1.96	.08			.93	T		T	
8			T	.94				1.74	T			
9			T	.04			.60	.08	.01		T	
10	.80							.13	.21		.48	
11	T									.34		
12		T					T			.07		
13		T										
14									.77	.94		
15			.07					.31		1.05		
16	.06				T	.04	T	.02	1.36	.07		
17		T		.07						.03	T	
18				.16	.12			.14				
19	T		T	.76	.95		T					
20		.89			.48	T			.17			
21		.61	T	.06	.53	T						
22		.40	.08	.14								
23						.52						
24	T			.98	1.12	.48	T					T
25	T			.16			T		1.04		.08	
26	T				1.15	T		.43	.84			T
27	T	.94			.40	T						T
28	T	.30					1.16					
29	.19		.06	.16	.04	.71						
30	.12		.02		.02	.22	.23		1.81			
31							.08				.02	
Total	1.17	3.44	1.45	7.08	6.47	2.87	3.46	3.90	6.27	2.52	.58	......
1916.												
1					T				T			
2					.04							
3												
4				.51		4.71						
5				.04		.48						
6				.61								
7	T			.02		T						
8				T				.55	.55		.42	T
9						.97		.11			.08	
10		T	T			T				T		T
11									1.21	.07	T	
12	T	T		T						.24	T	
13		T			T						T	T
14			T	.12		1.48		T				T
15				.59		.09		T		1.40		T
16												
17					.31	1.00						T
18	T					.38			T	T		
19	T									T		
20					T	.17						
21	.30				T			.18				.18
22		.03						T			.45	T
23			T						.44			
24	T					2.36				.10		
25	.89		T	.12					.02	.02		
26	.06		.38			T		.25				T
27	.04	T			.66						T	
28	T				.73							

TABLE II.—*Daily and monthly precipitation at Woodward, Okla., during the 5-year period from 1914 to 1918, inclusive*—Continued.

Date.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1916.												
29	T	T						T		0.04		
30	T			T				0.06				
31	T		0.54				T					0.2
Total	1.29	0.03	.92	2.01	1.74	11.64	......	1.15	2.22	1.87	0.95	.38
1917.												
1							.37	.19				
2			T			.26	.09		.02	T		
3			T		T		.10					
4	T											
5	T						T	T				
6					T			.01				
7								1.72				
8						.02		.12		T		.18
9					T			.01				
10					.07				.49			
11					.10		.02	.50				
12				.28				.66	T			
13	T		.28	.04	T			.86	T			
14			.06	T	.45			.02	T			
15	.16	.22		.22			T		T			
16	.03				T		T	1.20	.57			
17								.10		T	.65	
18							.35		.42		.10	
19				.60	T	T	.37		.32		T	
20					.43	.17	T					
21	.24				T	1.20						
22	T				T		T					
23	T					.19	.03	.55				
24						T						
25				T	.08			.07				T
26			T	.03					.08			
27					.26				T			
28				.14				.66			.02	
29						.05		.33		T		
30				.62								
Total	.43	.22	.34	1.93	1.39	1.89	1.33	7.00	1.90	T	.77	.18
1918.												
1						T			T			
2			.10				.06		.04		T	
3			1.04						.09			
4			.06		T				.72			
5					T	T			.01			
6				.36	.04				.13		T	
7						.51					.83	
8						.88		.04				
9		T			T	.02		T	T	T		
10	.09						T	T				
11	.38	.04					T					
12		.07			.41							.24
13				T			T					T
14	T			.10				T			T	
15				1.36			.32		T		T	
16	.93						1.22	T	.10		T	.52
17				T	.17		.04	T			.05	.10
18				.13			T					.36
19	.06			.41			T			.44		.86
20				.12						.02		
21				.03								
22			T				.06	T		1.65		
23					.07		.09	.51		.22	T	1.20
24							T	.01		T	.85	.20
25									.12			
26					.26				.05	.75		
27	T	T			.08	.21				.46	T	
28	.14	.11	.25	T	.87							
29			.40		2.32	.13	T					
30						.36		.14				
31					.27							.10
Total	1.60	.22	1.85	2.51	4.49	2.11	1.79	.70	1.26	3.54	1.73	3.58

Humidity.

The atmospheric humidity of this section is low on the average. It decreases and the wind velocity increases from the central part of Oklahoma westward. The usually low humidity at Woodward no doubt plays an important part in influencing transpiration from the growing crops.

TABLE III.—*Monthly climatic data, covering temperature and wind movement, recorded at the Woodward (Okla.) Field Station in the six months, April to September, inclusive, of each year during the 5-year period from 1914 to 1918, inclusive.*

Season and month	Temperature.					Wind.			
	Mean.	Maximum.		Minimum.		Prevailing direction.	Monthly movement.	Highest day.	
		Reading.	Date.	Reading.	Date.			Movement.	Date.
Season of 1914:		°F.		°F.			Miles.	Miles.	
April	57	96	16	24	8	N.	7,344	440	21
May	65	92	10	40	[a]8	S.	6,845	400	10
June	80	103	28	52	28	S.	7,920	463	7
July	81	106	[a]29	57	9	S.	4,613	298	22
August	79	101	20	60	[a]11	S.	4,836	316	23
September	74	100	10	40	30	S.	5,688	331	13
Season of 1915:									
April	61	92	28	28	[a]1	S.	6,768	481	4
May	63	92	13	37	7	E.	5,952	413	25
June	72	100	20	44	8	E.	5,544	351	11
July	78	99	12	50	5	S.	5,580	342	7
August	73	99	17	41	31	E.	3,050	189	7
September	72	99	10	46	27	S.	4,248	302	13
Season of 1916:									
April	53	88	[a]11	20	9	SW.	6,624	445	19
May	68	105	7	32	1	SW.	6,770	446	10
June	73	101	1	52	6	E.	5,976	478	22
July	80	103	19	55	[a]7	S.	4,241	235	2
August	81	104	[a]3	46	28	SW.	5,506	287	10
September	70	98	12	31	29	SW.	5,904	381	27
Season of 1917:									
April	55	91	22	23	2	NW.	8,237	507	16
May	60	98	17	30	8	SW.	6,653	475	17
June	76	109	12	41	[a]2	S.	6,720	495	11
July	83	108	13	56	12	SW.	5,597	300	29
August	76	100	4	45	29	SE.	3,774	234	5
September	71	102	7	36	27	SE.	3,257	247	25
Season of 1918:									
April	51	82	1	29	[a]10	NE.	5,678	360	14
May	69	99	8	34	1	SE.-SW.	8,129	462	19
June	79	106	24	58	[a]1	SW.	4,649	295	30
July	80	103	15	53	1	SW.	4,745	420	4
August	84	105	[a]3	50	31	SW.	4,680	262	6
September	66	102	15	34	[a]20	SW.	3,874	266	24

[a] Other dates also.

Wind.

Monthly data on wind are shown with other data in Table III for the crop season (April to September) in the 5-year period from 1914 to 1918, inclusive. The wind velocity for the season averages high. Some days are calm; then there are other days when the wind moves at a very high velocity. The highest total movement for one day during that period was 507 miles, which occurred on April 16, 1917. This is an average of more than 21 miles an hour for the entire day. Such high winds may cause great damage either by covering up the young plants, by cutting them off with moving particles of soil, or by blowing down the crop when it is approaching maturity.

Temperature.

The daily range in temperature is large. In summer the days are warm to hot, but the nights usually are cool. The data on mean, maximum, and minimum temperatures and the dates, by months, for the season (April to September) in the 5-year period from 1914 to 1918, inclusive, are given in Table III, which also contains data on wind movement.

The temperature in winter seldom reaches zero, but occasionally even lower temperatures occur. In summer the temperature reaches the 100° F. mark and above quite frequently. The maximum temperature in this 5-year period, 109° F., was recorded on several dates in June, 1917. The average date of the last spring frost is April 11, and that of the first fall frost, October 25, leaving an average frost-free period of 196 days.

Evaporation.

In the district here described the loss of moisture by evaporation is very great. The chief factors that influence evaporation are precipitation, wind, and temperature. The maximum evaporation naturally occurs in periods of high temperatures, low rainfall, and strong winds.

TABLE IV.—*Monthly seasonal and average monthly precipitation and evaporation at the Woodward (Okla.) Field Station during the six months from April to September, inclusive, in the 5-year period from 1914 to 1918, inclusive.*

[Data (in inches) furnished by the Office of Biophysical Investigations, Bureau of Plant Industry.]

Year.	April.		May.		June.		July.		August.		September.		Total.	
	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.
1914	1.7	6.8	3.2	6.2	0.6	11.3	1.9	10.9	2.6	8.9	0.6	8.4	10.5	52.6
1915	6.5	6.0	5.3	6.7	2.4	6.6	3.1	10.0	3.6	6.5	5.7	5.8	26.8	41.7
1916	2.3	6.0	1.7	9.8	10.3	7.7	0	10.4	1.0	11.2	2.3	7.5	17.6	52.6
1917	1.6	7.2	1.0	7.0	1.4	11.3	1.1	11.7	6.9	7.4	2.0	5.0	14.0	49.6
1918	2 2	5.0	4.0	9.3	1.9	8.7	.7	10.1	1.3	11.0	1.2	5.8	11.3	49.9
Average	2.9	6.2	3.0	7.8	3.3	9.1	1.4	10.6	3.1	8.0	2.4	6.5	16.0	4 .3

Table IV contains a comparison of the monthly precipitation and evaporation records made at the Woodward Field Station during the six months from April to September in each year of the 5-year period from 1914 to 1918, inclusive. The evaporation measured is from the free water surface of a tank 8 feet in diameter. The evaporation was more than three times as great as the precipitation during that period. The maximum monthly evaporation, 11.7 inches, in this 5-year period, occurred in July, 1917. During that same month the precipitation amounted to only 1.1 inches. The 5-year average evaporation for July was 10.6 inches, and that of the precipitation 1.4 inches. The averages for August are 8 inches of evaporation and 3.1 inches of precipitation. Such high evaporation and low precipitation have a bad effect on plant growth and are contributing causes to certain unfavorable crop results in various years.

THE WOODWARD FIELD STATION.

The Woodward Field Station, located 1 mile southwest of the main part of Woodward, Okla., was established by the Office of Dry-Land Agriculture during the autumn of 1913, and the first crop was produced the following season. The farm consists of 160 acres of bench land. Most of the soil at the station is a light phase of sandy loam which is classified as Canadian sandy loam. Some soil blowing has occurred at the station but has never been serious.

Woodward is centrally located in the western broom-corn area, and conditions are fairly representative of the transition belt which extends north and south between the high plains on the west and the prairie region to the east. The principal crops of the surrounding country are milo, kafir, broom corn, and winter wheat, with some corn and alfalfa grown on bottom lands. The results of the experiments with broom corn at this station should be applicable to the greater part of the western broom-corn area.

THE BROOM CORNS.

Broom corn is a specialized sorghum, closely related to sweet sorghum. It consists of two rather distinct groups of varieties. These react differently to environmental conditions and therefore give different results. To understand these results it is necessary to know the characters by which the groups differ from each other.

CLASSIFICATION.

The two groups of broom corn differ mainly in the height of the plants, in the tenacity of the attachment of the peduncle to the upper node, and in the length and texture of the brush.

Standard broom corn grows to a height of 8 to 10 feet under the conditions obtaining at the Woodward Field Station. Under more favorable conditions farther east it reaches a height of 12 to 15 feet. The leaves vary from 9 to 11 in number. The heads range in length from 18 to 24 or more inches. They are well exserted from the boot or upper leaf sheath and firmly attached to the upper node, which makes necessary the use of a knife in harvesting the brush. The fiber is coarse, but usually round and pliable.

Dwarf broom corns range in height from 3.5 to 6 feet, with short internodes. The leaves are narrow, dark green, and from 10 to 13 in number. The heads range in length from 15 to 22 or more inches under quite favorable growing conditions, but remain from one-half to one-third inclosed in the upper sheath. They are not as firmly attached to the upper node, which makes harvesting possible without the aid of a knife by pulling or jerking the heads from the standing stalks.

EXPERIMENTAL CONDITIONS.

In order to gain a better understanding of the experimental results obtained from the varieties included in the different experiments, it is necessary to know the methods of obtaining the data recorded and the conditions prevailing each season.

Methods Employed.

The methods employed in regard to the size and arrangement of the plats, the crop rotation practiced on the experimental area, the date on which the varietal experiment was sown each year, and the method of collecting certain agronomic data are explained in the following paragraphs.

SIZE AND ARRANGEMENT OF PLATS.

The land used in these experiments is divided into series which are 8 rods wide, extending the whole length of the field from north to south. These series are separated by roads 20 feet wide. The rows of broom corn extend across the series from east to west and are spaced 3.5 feet apart. Thus, each row occupies a space 8 rods long and 3.5 feet wide and represents approximately one-hundredth of an acre. Seeding is begun at either end of the series and continued until the entire series is finished. No alleys are left between the varieties, so there is no border effect except at the ends of the rows, where they border on the roads. Each variety usually occupied 10 rows, or a tenth of an acre. In sowing the varieties the rows were made longer than 132 feet, extending several feet into the roadway at both ends. When the plants had attained a height of 12 to 15 inches the ends of the rows were trimmed to the proper limits.

CROP ROTATION PRACTICED.

It has not been practicable to follow a definite system of crop rotation in these experiments, because the land available for this work was all in sod the first year (1914), and only enough could be prepared for immediate use. The pressure of other work prevented breaking new sod in time for the 1915 crop, so the same land was used as in 1914. Later in the season more sod was broken. This sod land was fallowed and used for the 1916 crop. In 1917 the varietal experiment followed the same crop, and the other experiments followed cowpeas. In 1918 the varietal experiment followed cotton, and the other experiments followed broom corn.

METHOD OF SEEDING.

A 2-row combined corn and cotton drill fitted with sorghum plates was used for sowing the crop from 1914 to 1916, inclusive. Since then a 2-row drill fitted with a special plate, which is thinner than the ordinary sorghum plate, has been used. This plate contains 36 holes, each three-sixteenths of an inch in diameter. The feed was run on high gear, which drops at intervals of about 3 inches. It was desired to have only one kernel dropped at a time, and the above-described plate was designed to accomplish that end; but in many cases two and occasionally three kernels were dropped, because the kernels vary in size.

Broom-corn seed usually remains inclosed in the glumes or hulls, but some seed is dehulled by the thrasher. Seeds free from glumes will pass through a much smaller hole than the seed remaining in the hulls. This makes a drop of a single kernel each time impossible where the dehulled seeds are mixed and the holes in the plates are large enough to drop seeds covered with a hull.

Seeding was done at a rate heavy enough to insure a thick stand under normal conditions, with the idea of obtaining a stand sufficient for these experiments if the conditions were unfavorable. When the plants were from 6 to 10 inches high the plats were thinned by hand to the stands desired in the different experiments.

DATES WHEN THE CROPS WERE SOWN.

The dates on which the crops in the varietal, rate-of-seeding, and spacing experiments were sown each year are as follows: In 1914, all three experiments were sown on May 14. In 1915 the varietal and the rate-of-seeding experiments were sown on May 25 and the spacing experiment on the following day. In 1916 the spacing experiment was sown on May 19 and the other two on May 22. In 1917 the spacing experiment was sown on May 18 and the others on May 24. In 1918 the varietal and rate-of-seeding experiments were sown on May 27 and the spacing experiment on June 3.

METHODS OF COLLECTING DATA.

The data on plant and stalk spaces and on the occurrence of suckers and heads were obtained by actual counts of the plants, stalks, and heads in all the rows of each variety for which such data are presented. The percentage of suckers is determined by dividing the difference between the number of stalks and the number of plants by the number of stalks. The percentage of headed stalks is the number of stalks that bore heads divided by the total number of stalks in the plat. The growing period as given here is the total time elapsing from seeding until the brush is harvested, usually when in the dough stage. The vegetative period is the time from seeding until the heads appear. If growing conditions are unfavorable and heading is progressing slowly and unevenly, this period is prolonged but counted as ended when heads cease to appear. The fruiting period is the completion of the vegetative period or the time from the appearance of the heads until the brush is considered ready to harvest.

The height of the plants is the average of several measurements made at different points in the plat. The heads are included in these measurements and considered as standing erect, though most of them droop, which gives the stalks the appearance of a lower height.

The standard varieties are harvested by tabling the stalks so that the heads are brought within easy reach. Then the heads are cut off with a jackknife, leaving about 6 inches of stem with the head. The Acme and Dwarf varieties are harvested by pulling or jerking the heads from the standing stalks. The heads are taken at once to the curing shed and thrashed. Then the thrashed brush is placed in layers, about 3 inches thick, on shelves in racks to cure. After the brush is cured, which requires about two weeks, depending somewhat upon the weather conditions, it is graded. This is done by sorting by hand the good brush from the poor. Each lot is then weighed and the acre yields are computed therefrom. The combined weight of the two grades is the total yield per acre.

Brush with long, round, straight fiber without heavy center stems is graded good quality, and short, spiky brush with large center stems and that with crooked brush or coarse, flat fiber is graded poor quality. Heads with fiber of good and poor quality are shown in figure 3.

The length of the brush in each grade is the average length of 10 heads picked at random from each lot after it is graded.

The percentage of good brush is the weight of that grade divided by the combined weight of both grades, or the total yield of the plat.

Environing Conditions.

A brief summary of the environing conditions during the 5-year period from 1914 to 1918, inclusive, is given to aid in the interpretation of the results obtained during that period.

The season of 1914 was not favorable to high yields. The rainfall for the first four months of the year was below normal, which left the soil without much stored moisture. One good soaking rain

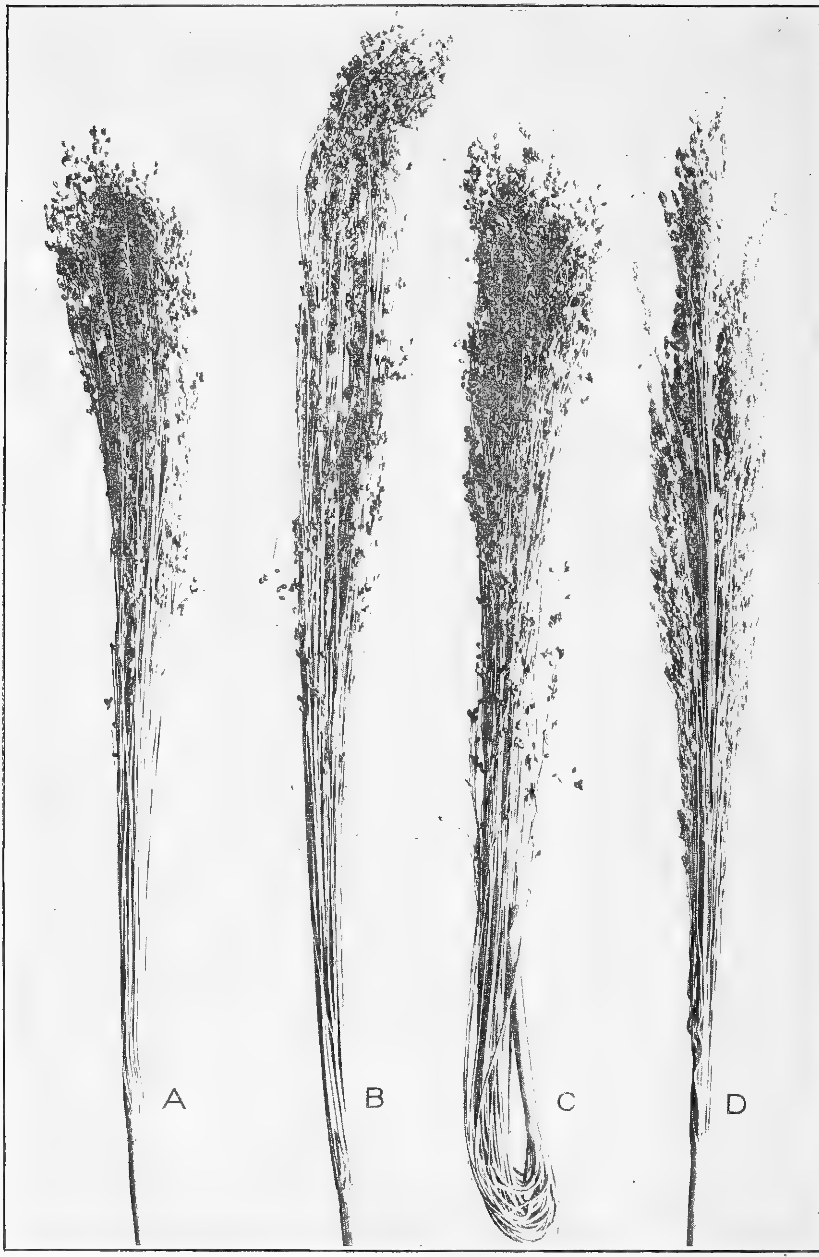

FIG. 3.—Heads of broom corn: (A) Good type, round fiber; (B) coarse, flat fiber; (C) crooked head; and (D) poor, short fiber and a large central stem.

of 1.96 inches occurred on the first day of May. There were 13 light showers, well distributed throughout the remainder of the month, but none of these was sufficient to furnish stored moisture for future use. June was extremely dry, with only one rain of 0.61 inch, which fell on the 15th of the month. The next rainfall of value did not come until July 6. During the remainder of July there was only one rain. The rainfall for August was below normal and over half of it fell in the last five days of the month, which was too late to benefit the crop, which had been sown the middle of May.

The season of 1915 was extremely wet. The rainfall for each of the first 10 months of the year was above normal. During the growing season there was no time that the crop lacked moisture. This resulted in unusually high yields in all varieties.

The year 1916 was variable and unfavorable. The total precipitation, which was about normal, was quite unevenly distributed. The rainfall in April was normal, but for May it was only about half of the normal. The precipitation for June amounted to 11.64 inches, which is about 8 inches above the normal for that month. More than 5 inches of this fell on the 4th and 5th, but the remainder was fairly evenly distributed throughout the rest of the month. July was bone dry; August was short by nearly two-thirds and September by almost one-third of the normal supply. Crops so seeded that the critical growing stage of the plants did not occur in a droughty period made fair to good yields, but otherwise both yield and quality of brush were affected.

The season of 1917 was not favorable to the production of broom corn of good quality. The rainfall for May, June, July, and September was considerably below the normal of those months, while the rainfall for August was 7 inches, which was nearly half of the total precipitation for the entire year, or 3.5 inches above the normal for that month.

The crop season of 1918 was the poorest in the 5-year period under consideration. The rainfall in April and May was about normal and fairly well distributed, which furnished moisture sufficient to start the crop in good condition; but June was dry, and July was drier still. The rainfall for August amounted to only seven-tenths of an inch, and this fell on four different days, which made it of little value to the crop. The temperature for the three months, June, July, and August, was high, as was also the evaporation. These conditions, together with the law rainfall, made growth practically impossible at times, which resulted in the lowest yields in five years.

VARIETAL EXPERIMENTS.

The objects of the varietal experiments were to determine the adaptation and value of the different groups of broom corn and the best varieties in each group.

The results obtained from all the lots and selections of all varieties included in these experiments in any or all of the five years from 1914 to 1918, inclusive, are presented in the tables that follow. All the agronomic data that are available, so far as they serve to show the comparative response of the different varieties to environing conditions each season, are presented.

The data in the tables include not only the yields, therefore, but the row space occupied by each plant and each stalk; the length in days of the vegetative and fruiting periods and of the total growing period; the percentage of suckers and of stalks headed; and the height of the plants. The yield (in pounds) of good and poor brush and the total yield of brush per acre are shown. The average length of the brush of each quality and the percentage of good brush in the total yield are also given.

The tabulated data show clearly that the Dwarf varieties of broom corn outyield the Standard varieties under such conditions as exist at Woodward, Okla. The Dwarf varieties evidently require less water and therefore are better adapted to the conditions obtaining in the district described than the Standard varieties.

STANDARD BROOM CORN.

The groups of broom corn have been described previously. Many varietal names are applied to each group; but these are not significant in most, if not all, cases, as they do not represent distinct varieties. Some of the names applied to Standard broom corn are: Australian, California Golden, Chinese Evergreen, Early Long-brush Evergreen, Evergreen, Imperial Evergreen, Improved Evergreen, Missouri Evergreen, and Tennessee Evergreen. In many cases these are local names. The grower should know that he has seed of high germination, selected from brush of good quality. The manufacturer is not particularly interested in the name applied to the brush. What he wants to know is the quality of the brush he is buying. This he can not determine by the name, but instead must see the brush itself.

The results obtained with the Standard variety in the varietal experiment are shown in Tables V and VIII. From 1914 to 1916, inclusive, one plat only of this variety was grown each year. The source of that variety (C. I. No. 556) is supposed to be Florence, Italy. The stock seed used in the experimental work was obtained by the senior writer in 1914 from Lindsay, Okla., the original seed having been imported two years previously. The field at Lindsay from which this seed was selected was of uniform height and produced a crop of good brush. The fiber was round, pliable, of medium size, and of uniform length.

In 1917 two more strains (C. I. Nos. 580 and 588) were included in the experiment. These were obtained in the spring of 1915 and grown for two years in 8-rod rows before being increased to tenth-acre plats. The former (C. I. No. 580) was obtained from a seed company in Houston, Tex., under the name "California Golden Dwarf," and the latter (C. I. No. 588) from a seed firm in New York, under the name "Evergreen." These strains are early, and for that reason were thought to be of probable value.

The vegetative period for C. I. No. 556, shown in Table V, ranges from 73 to 80 days for all years except 1917. In that year it was prolonged to 112 days, which was due to droughty weather conditions during the vegetative period. For the other two strains the vegetative periods in that same year were 95 and 100 days, respectively, which are 17 and 12 days shorter for these strains than for C. I. No. 556. The fruiting period usually occupies from 17 to 20 days, depending upon growing conditions. These early strains required less time than C. I. No. 556 by 9 and 7 days in 1917, and the fruiting period of the one grown in 1918 was shorter by 5 days. The other strain (C. I. No. 588) was discarded after one year. It was not as early as the one which is retained, and while the brush was of a greater average length the quality was not as good. The most objectionable feature was the construction of the head. Almost without exception the heads had a rachis or central stem from 3 to 4 inches in length.

The average row space per plant in the 5-year period ranged from 5.8 inches in 1915 to 8.6 inches in 1918. The plats were thinned by hand each year to approximate a stand of one plant to 6 inches of row space, as that appears to be about the right rate for the best results under Woodward conditions. The stalk space does not differ materially from the plant space, as the percentage of suckers is quite small. In 1914 and 1915 the suckers amounted to less than 1 per cent, and they were as much as 20 per cent in only one year. This occurred in 1918 in one variety, though the average for the two strains that year was only 14.9 per cent.

The yield per acre of brush is recorded in pounds. The yield of good quality is recorded first, then that of poor quality, and lastly the total yield, which is the combined weight of both qualities. The highest total yield was obtained in 1915, which was the most favorable season for high production in the 5-year period. But the percentage of good brush was lower in that year than in any other. This is natural, as seasonal conditions favorable to rapid growth are conducive to the development of coarse, kinky, or burly fiber and crooked heads. Table VIII shows the annual yields of all lots of broom corn included in this experiment, together with their average yields in periods of varying length.

TABLE V.—*Agronomic data for Standard broom corn grown in varietal experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

Year and variety.	Row space (inches).		Length of period (days).			Percentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Plants.	Stalks.	Vegetative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
Season of 1914:														
C. I. No. 556	6.7	6.7	77	17	94	0	79.6	6.5	225	75	300	22.0	14.0	75.0
Season of 1915:														
C. I. No. 556	5.8	5.8	80	21	101	0	94.4	8.3	440	235	675	22.0	22.0	65.2
Season of 1916:														
C. I. No. 556	8.0	7.5	73	18	91	6.6	86.1	7.0	366	39	405	22.0	15.0	90.4
Season of 1917:														
C. I. No. 556	7.0	6.5	112	20	132	6.0	80.8	7.0	350	31	381	18.5	16.5	91.8
C. I. No. 580	6.6	5.8	95	11	106	12.2	84.1	6.5	160	45	205	12.5	10.0	78.0
C. I. No. 588	6.5	6.3	100	13	113	3.0	79.0	7.0	200	33	233	14.5	12.0	85.7
Average	6.7	6.2	102	15	117	7.1	81.3	6.8	237	36	273	15.2	12.8	83.2
Season of 1918:														
C. I. No. 556	8.6	6.9	78	17	95	20.3	73.3	6.0	275	30	305	18.5	13.5	90.1
C. I. No. 580	6.7	6.0	63	12	75	9.6	83.7	5.5	356	22	378	17.5	12.5	94.1
Average	7.6	6.4	70	15	85	14.9	78.5	5.7	315	26	341	18.0	13.0	92.1

ACME BROOM CORN.

The Acme broom corn was developed from a selection made in a field of Standard broom corn by Mr. A. H. Leidigh, at Channing, Tex., in 1906. It resembles the Standard variety in the length and texture of the brush and the Dwarf in the height of the stalk. The peduncle, or main stem, is less firmly attached to the upper node, or joint, than it is in the Standard broom corn. This makes it possible to harvest it in the same way as the Dwarf variety. The Acme requires less water than the Standard, and it produces a brush of good length and quality under the average seasonal conditions obtaining in the southern Great Plains. These characters make it adapted to conditions in that section of the United States. It is now being grown there commercially to a limited extent. Plants of this variety are shown in figure 4.

The results with the Acme broom corn obtained in the varietal experiment conducted at the Woodward Field Station during the 5-year period from 1914 to 1918, inclusive, are shown in Tables VI and VIII. It will be noted in Table VI that in the 5-year period the row space per plant ranged from a minimum of 5.5 inches in 1915 to a maximum of 8.7 inches in 1916, with an average of 7.3 inches for the whole period. This is approximately the same stand as that of the other varieties, which makes comparison possible. This variety requires about 90 days to mature under average conditions. This time may be either lengthened or shortened by growing conditions; it was prolonged to 115 days in 1917, while it was only 84 days in 1918. Droughty weather when the crop is approaching the heading stage, changed to favorable growing conditions by rain during that stage, will prolong the vegetative period and make heading irregular, though the percentage of stalks headed may be high, as in 1917,

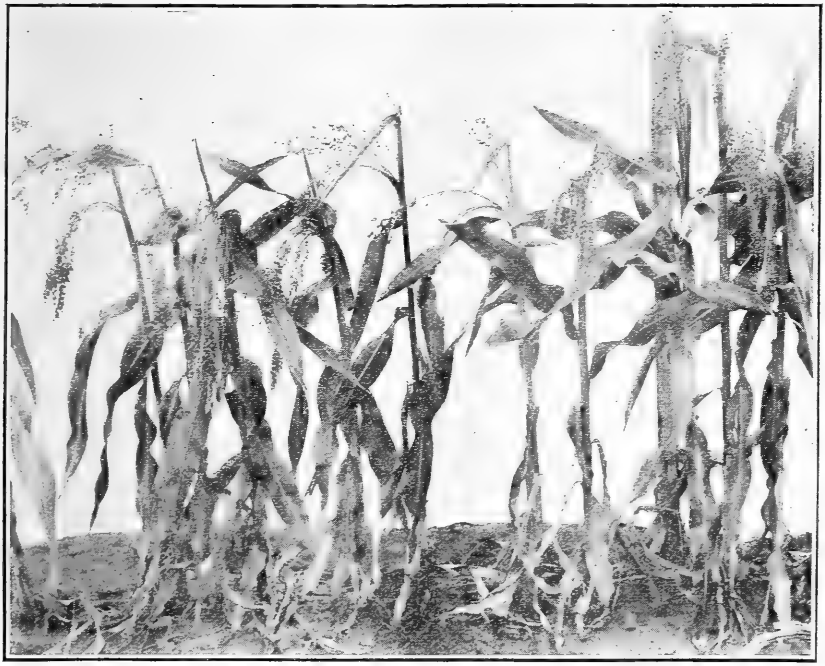

FIG. 4.—Plants of Acme broom corn (C. I. No. 243).

when 97.5 per cent of all stalks headed. The vegetative period may be shortened by the reversal of growing conditions from favorable to unfavorable just as the plants are approaching the heading stage. In such cases none except the early stalks produce heads. This results in the shortening of the growing period and in a low percentage of stalks headed, as was the case in 1918, when the crop required only 84 days to mature and produced only 66.6 per cent of heads.

The average height of the plants ranged from 3.5 feet in 1918, a very dry season, to 5.5 feet in each of the years 1915 and 1917, when seasonal conditions were more favorable. The plants are uniform in height, and the height compares favorably with the best strains of the Dwarf broom corn.

The yield and percentage of good brush vary with the season. However, a low yield of brush does not necessarily mean a small percentage of good quality. In 1918 the yield of good brush was at the rate of 283 pounds to the acre, which was 91.1 per cent of the total crop. In 1915 the yield of good brush was 600 pounds per acre, which was only 79.4 per cent of the total yield. The acre yield of good brush ranged from 283 pounds in 1918 to 600 pounds in 1915, with an average yield of 392 pounds in the 5-year period, which is an average of 88.5 per cent of the total brush produced in that period. The annual and the average yields are shown in Table VIII, where it will be noted that this variety ranked second in the 2-year average and tied with one Dwarf strain for first place in the 5-year average. In percentage of good brush it ranks first. This is shown graphically in figure 7.

TABLE VI.—*Agronomic data for Acme broom corn grown in varietal experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

Year and variety.	Row space (inches).		Length of period (days).			Percentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Plants.	Stalks.	Vegetative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
Season of 1914: C. I. No. 243	7.7	7.7	73	17	90	0	87.4	4.0	305	20	325	22.0	14.0	93.8
Season of 1915: C. I. No. 243	5.5	5.2	77	18	95	4.8	93.0	5.5	600	155	755	23.0	23.0	79.4
Season of 1916: C. I. No. 243	8.7	6.6	70	17	87	24.1	83.6	3.8	378	55	433	18.5	16.0	87.2
Season of 1917: C. I. No. 243	7.1	6.5	107	8	115	8.7	97.5	5.5	394	39	433	17.0	13.0	91.0
Season of 1918: C. I. No. 243	7.5	5.8	69	15	84	22.6	66.6	3.5	283	28	311	17.5	15.5	91.1
Average	7.3	6.4	79.2	15	94.2	12.0	85.6	4.5	392	59.4	451	19.6	16.3	88.2

DWARF BROOM CORNS.

Dwarf broom corn came into prominence during the early nineties, owing to its adaptation to dry-land conditions. Since then the center of production of the broom-corn crop has moved from Illinois westward into Oklahoma. Most of the crop grown in Oklahoma and adjacent States is of the Dwarf variety except in the Lindsay district of Oklahoma, which includes the Washita bottom lands in Garvin, Grady, and McClain counties. As in the case of the Standard variety, many names are applied to the Dwarf broom corn. Some of the most common of these are California Golden Dwarf, Dwarf, Dwarf Evergreen, Evergreen Dwarf, Japanese Dwarf, and

Oklahoma Dwarf. These names are mostly local and do not represent different varieties.

The Dwarf broom corn used in the varietal experiment included three different lots in the first three years, from 1914 to 1916, inclusive. In 1917 three more lots were added, making a total of six grown in that year. One was added in 1918, which made seven for that year. In all, a total of seven different lots and 22 plats were grown in the 5-year period from 1914 to 1918, inclusive. These lots were obtained from different sources, most of them widely separated.

C. I. No. 442 was obtained from a grower at Sterling, Kan., in 1911, and has been grown at the Amarillo (Tex.) Field Station since

Fig. 5.—Plants of Dwarf broom corn (C. I. No. 442).

that time. Plants of this strain are shown in figure 5. C. I. No. 535 is the result of a selection made by the senior writer in 1912 from a crop grown at the Amarillo station that year from bulk seed obtained from a grower near Amarillo, Tex. The crop from which this selection was made was evidently a mixture of Standard and Dwarf varieties, as it was quite variable in height and type of brush.

C. I. No. 557 was obtained from a grower at Elk City, Okla., in 1914. He had been growing this strain in large quantities for a number of years, distributing the seed commercially under the name Evergreen Dwarf. It is a good variety, well adapted to dry lands, which produce a high yield of good brush under average conditions.

C. I. Nos. 559, 564, 595, and 597 were obtained from different seed companies and grown in 8-rod rows at the Woodward Field Station for two or three years before being included in the varietal experiment.

The agronomic data for Dwarf broom corn are shown in Table VII, while the annual and average acre yields are shown in Table VIII, where comparisons with the Standard and Acme varieties are made.

The row space per plant in the different lots does not vary more than about an inch in any one year, while the average row space for all lots in the same year ranges from 6.3 inches in 1915 to 8.6 inches in 1916. From this standpoint the Dwarf varieties are directly comparable with the other varieties used in the experiment.

The total growing period of the three lots grown during the entire 5-year period ranged from 84 days in 1918 to 114 days in 1917, with an average of 94 days for the period. This is the same average period as for the Acme, but 9 days less than was required by the Standard, which was 103 days in the same period. The average proportion of suckers in these same three lots is 15.5 per cent, which is 3.5 per cent greater than for Acme and about three times as high as for the Standard, C. I. No. 556.

In height C. I. No. 442 is consistently lower than any of the other lots. Its height ranged from 2.3 feet in 1918 to 4.3 feet in 1915. While the other two lots are of practically the same height in most years, they show a difference of 6 inches in 1917, each reaching its maximum of 5 and 5.5 feet, respectively, in that year. The new lots added in 1917 compare favorably in height with the two just mentioned.

The average yield of good brush by the three lots grown during the entire 5-year period ranged from 240 pounds in 1918 to 615 pounds in 1915. The average total yield produced in these same two years was 278 and 752 pounds, respectively. The yield of good brush was 85.8 per cent and 82.2 per cent of the total yield. The higher percentage of good brush was produced in 1918, when the lowest total yield was made, and the lower percentage in 1915, when the highest total yield was made. This tends to show that the percentage of good brush does not depend so much upon the quantity of brush produced as on the conditions under which it is grown. Growth that is too rapid or too slow during the fruiting period has a bad effect on quality. The former makes coarse, burly, or twisted brush and crooked heads, while the latter causes the brush to be short and spiky. The greatest average length of good brush, 21.7 inches, was produced in 1915, and the shortest, 15.5 inches, in 1917. In the former year the length of the poor brush was the same as the good, but the crop made a rapid growth and developed some coarse, twisted brush. In the latter year growth was retarded, so that a number of short, spiky heads developed which were of poor quality and averaged only 13.2 inches in length. The lowest average percentage of good brush in the 5-year period was made in 1916. In that year the length of good brush averaged 18.8 inches, but it amounted to only 80.9 per cent of the total crop. The same year the average length of the poor brush was only 14.7 inches, or 4 inches less than the good brush. This was due to extremely dry conditions in the latter half of the heading period.

TABLE VII.—*Agronomic data for Dwarf broom corn grown in the varietal experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

Year and variety.	Row space (inches).		Length of period (days).			Percentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Plants.	Stalks.	Vegetative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
Season of 1914:														
C. I. No. 442	6.5	6.5	73	18	91	0	83.4	3.5	275	20	295	18.0	15.0	93.2
C. I. No. 535	7.5	7.5	73	18	91	0	82.1	3.8	225	20	245	18.0	12.0	91.8
C. I. No. 557	6.5	6.5	73	18	91	0	77.4	4.0	250	100	350	21.0	14.0	71.4
Average of 3	6.8	6.8	73	18	91	0	80.9	3.8	250	47	297	19.0	13.7	85.5
Season of 1915:														
C. I. No. 442	6.3	5.2	81	14	95	17.3	72.7	4.3	511	83	594	21.0	21.0	86.0
C. I. No. 535	6.9	6.0	74	21	95	12.3	96.3	4.8	683	122	805	22.0	22.0	84.8
C. I. No. 557	5.7	5.3	76	19	95	7.0	100.0	5.0	650	205	855	22.0	22.0	76.0
Average of 3	6.3	5.5	77	18	95	12.2	89.7	4.7	615	137	752	21.7	21.7	82.2
Season of 1916:														
C. I. No. 442	9.2	5.3	72	15	87	41.7	75.9	3.0	283	117	400	17.0	13.5	70.8
C. I. No. 535	9.0	5.9	65	22	87	33.8	81.9	3.8	433	50	483	19.0	14.5	89.7
C. I. No. 557	7.6	6.8	70	17	87	10.7	86.9	3.8	361	78	439	20.5	16.0	82.3
Average of 3	8.6	6.0	69	18	87	28.7	81.6	3.5	359	82	441	18.8	14.7	80.9
Season of 1917:														
C. I. No. 442	7.1	5.9	96	16	112	16.6	94.5	4.0	328	72	400	14.0	12.0	81.9
C. I. No. 535	7.8	7.0	96	18	114	10.0	93.0	5.0	378	72	450	17.0	13.5	84.0
C. I. No. 557	6.8	5.9	109	8	117	12.8	91.2	5.5	378	77	455	15.5	14.0	82.9
Average of 3	7.2	6.3	100	14	114	13.1	92.9	4.8	361	74	435	15.5	13.2	82.9
C. I. No. 559	6.8	6.5	116	17	133	3.0	87.4	4.5	444	45	489	16.5	12.0	90.9
C. I. No. 595	7.5	4.8	107	15	122	35.7	85.3	5.0	365	80	445	16.5	12.5	82.0
C. I. No. 597	7.6	6.8	107	15	122	10.7	95.5	5.5	411	50	461	17.0	14.0	89.2
Average of 3	7.3	6.0	110	16	126	16.5	89.4	5.0	407	58	465	16.7	12.8	87.4
Average of 6	7.3	6.2	105	15	120	14.6	91.1	4.9	384	66	450	16.1	13.0	85.1
Season of 1918:														
C. I. No. 442	7.6	5.3	66	19	85	30.1	59.3	2.3	188	37	225	14.0	13.5	83.3
C. I. No. 535	6.9	5.6	67	17	84	18.7	57.3	3.5	239	50	289	19.5	14.0	82.7
C. I. No. 557	7.2	5.6	69	15	84	21.4	70.4	3.5	294	28	322	16.5	13.5	91.4
Average of 3	7.2	5.5	67	17	84	23.4	62.3	3.1	240	38	278	16.7	13.7	85.8
C. I. No. 559	6.3	5.7	86	22	108	10.6	15.2	4.3	75	10	85	16.5	13.0	87.1
C. I. No. 564	7.8	6.5	70	25	95	16.7	58.2	4.0	178	22	200	16.5	12.5	88.9
C. I. No. 595	7.7	5.0	67	19	86	35.1	56.9	3.5	278	44	322	19.5	15.0	86.2
C. I. No. 597	8.0	5.6	70	16	86	29.9	58.7	3.5	294	25	319	18.5	15.5	92.2
Average of 4	7.5	5.7	73	21	94	23.1	47.3	3.8	206	25	231	17.8	14.0	88.6
Average of 7	7.3	5.6	70	19	89	23.2	53.5	3.5	221	31	252	17.3	13.9	87.4

COMPARATIVE YIELDS IN THE VARIETAL EXPERIMENTS.

The annual and average acre yields of brush of good and of poor quality from all the selections in all three groups of broom corn grown in the varietal experiments are shown in Table VIII. The

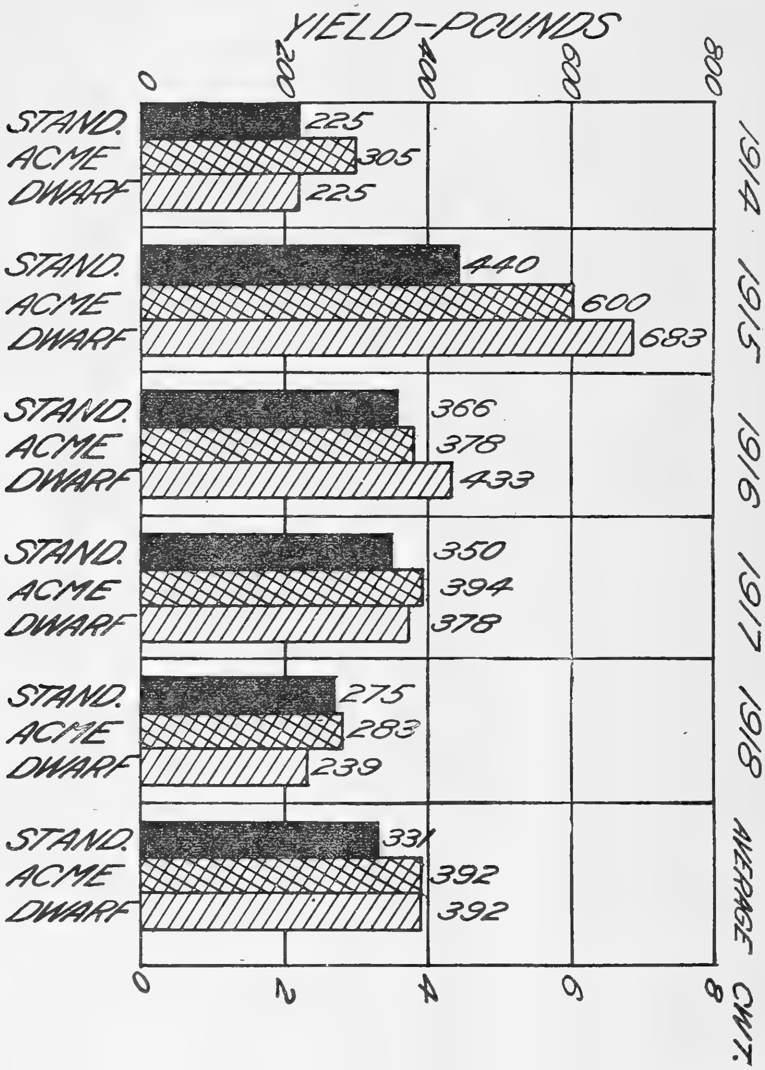

FIG. 6.—Diagram showing the annual and average acre yields of good brush of the Standard, Acme, and Dwarf broom corn grown in varietal experiments at the Woodward Field Station during the 5-year period from 1914 to 1918, inclusive.

average yields are given first for the two years, 1917 and 1918, in order to compare a few selections grown only in those years. The average yields in the full 5-year period from 1914 to 1918, inclusive, are given for all selections grown for that length of time.

Table VIII shows that a selection of Dwarf broom corn (C. I. No. 597) made the highest average yield of good brush in the 2-year period, with the Acme variety taking second place, while several other Dwarf selections are close competitors for third place. In the 5-year period, the Acme and the Dwarf (C. I. No. 535) tie for first place, with an average yield of 392 pounds of good brush. The

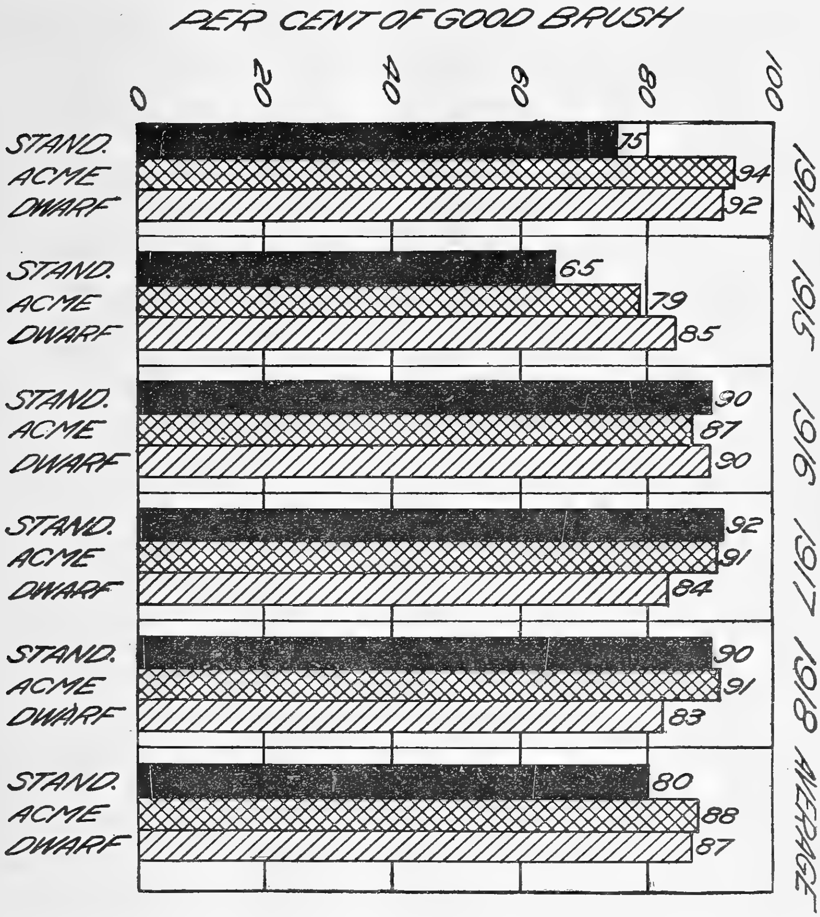

FIG. 7.—Diagram showing the annual and average percentage of good brush in the total yield produced by the Standard, Acme, and Dwarf broom corn grown in varietal experiments at the Woodward Field Station during the 5-year period from 1914 to 1918, inclusive.

Dwarf (C. I. No. 557), with an average yield of 387 pounds, or only 5 pounds less, takes a close second place, and the Standard (C. I. No. 556) takes third place, with an average yield of 331 pounds in this period. The 5-year average yield of the Standard, Acme, and Dwarf varieties is shown graphically in figure 6.

From the standpoint of the percentage of good brush in the total yield produced in the 5-year period from 1914 to 1918, inclusive, the

Acme stands first, with an average of 88 per cent, while the Dwarf (C. I. No. 535), is a close second, with an average of 87 per cent. This selection leads the next highest selection, Dwarf (C. I. No. 442), by 4 per cent, while the other two varieties, one Standard and the other Dwarf, grown in that period, tie for fourth place, with 80 per cent each. The percentage of good brush produced by the Standard, Acme, and Dwarf varieties is shown graphically in figure 7.

TABLE VIII.—*Annual and average acre yields of all lots of broom corn grown in varietal experiments at the Woodward (Okla.) Field Station during periods of varying length in the five years from 1914 to 1918, inclusive.*

Variety.	Annual acre yields (pounds).										Average yields.			
	1914		1915		1916		1917		1918		2 years, 1917 and 1918.		5 years, 1914 to 1918.	
	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.
Standard:														
C. I. No. 556	225	75	440	235	366	39	350	31	275	30	312	30	331	82
C. I. No. 580	......	......	......	......	......	......	160	45	356	22	258	33	......	......
C. I. No. 588	......	......	......	......	......	......	200	33	......	......	......	......	......	......
Acme:														
C. I. No. 243	305	20	600	155	378	55	394	39	283	28	338	33	392	59
Dwarf:														
C. I. No. 442	275	20	511	83	283	117	328	72	188	37	258	54	317	66
C. I. No. 535	225	20	683	122	433	50	378	72	239	50	308	61	392	63
C. I. No. 557	250	100	650	205	361	78	378	77	294	28	336	52	387	98
C. I. No. 559	......	......	......	......	......	......	444	45	75	10	259	27	......	......
C. I. No. 564	......	......	......	......	......	......	......	......	178	22	......	......	......	......
C. I. No. 595	......	......	......	......	......	......	365	80	278	44	321	62	......	......
C. I. No. 597	......	......	......	......	......	......	411	50	294	25	352	37	......	......

DATE-OF-SEEDING EXPERIMENTS.

A date-of-seeding experiment with Acme broom corn was conducted each year during the 5-year period from 1914 to 1918, inclusive. The plats used in this experiment were one-tenth acre in size. Seeding was done at intervals of one to two weeks. In 1914 the experiment included only three different dates. These were increased to four dates in 1915, to six dates in 1916, and to seven dates each in 1917 and 1918.

Table IX shows the agronomic data for Acme broom corn in the date-of-seeding experiment. It will be noted in this table that the stands obtained in the different dates of seeding in the same year and in the different years are comparable in almost all cases except those of the last date, July 3, 1917, and the first three dates in 1918. The thin stand in the former case was due to the dry condition of the soil and to high temperature at and following the date of seeding. Germination was low, and a number of the young plants did not have vigor enough to withstand the heat after they emerged. In 1918 the thin stands were due to the poor quality of the seed used. This seed was slightly frosted before harvest the previous year. Though it showed a fairly high germination in laboratory tests made prior to seeding time, it evidently was losing its vitality will age, as the stand of each successive seeding was thinner than that of the preceding one. For the last three dates in 1918, seed from another source was used, which gave a stand comparable with the stands in the other years.

The shortest total growing period required by the crop from any one date of seeding was 73 days, which resulted from the seeding made on April 16, 1917. In any one of the first three years, 1914, 1915, and 1916, the variation in the duration of the total growing periods of plats sown at different dates amounted to about 15 days. In the 3-year period the greatest variation amounted to 24 days. In 1917 the time required for the crop to mature was much longer than it was in any other year. In that year the shortest time was 100 days from the June 2 seeding and the longest time 137 days from the April 16 seeding. The abnormally long time required by the crop was due to the very unfavorable growing conditions which obtained in varying degrees through the months of May, June, July, and September. The moisture in August was enough to promote normal plant growth. The unusually short time required to reach maturity by the crop sown on July 1, 1916, was due to the lack of moisture at and following the time the crop was heading. Only 79.3 per cent of the total number of stalks in the crop produced heads.

Suckering is influenced largely by growing conditions and varies widely in the same variety when grown under different conditions. In 1914 the suckers amounted to less than 1 per cent of the total number of stalks resulting from any one of the dates of seeding, while in 1915 they ranged from 4.8 per cent to 28.1 per cent of the total. The percentage in 1916 varied about the same as it did in 1915, but it shows quite an increase in 1917, reaching 40 per cent in the July 3 seeding. However, a still wider variation occurred in 1918, when the highest was 62.8 per cent and the lowest only 6.5 per cent. This is a difference of 56.3 per cent, which was due to differences in stand and other environing conditions.

The percentage of stalks that head is influenced largely by growing conditions at heading time. When there is sufficient moisture to develop normal plant growth throughout that stage the percentage of heads developed to total stalks will be much larger than will be the case otherwise. There may be as wide a variation in the percentage of heads developed in plants sown at different dates in the same year as in plats sown on the same date in the different years. The lowest, 60.7 per cent, in the 5-year period was from the seeding made June 1, 1918, and the highest, 97.5 per cent, was from the seeding made on May 24, 1917. In the former case it will be noted in Table II, which shows the daily and monthly precipitation, that the crop was grown under very dry conditions. In the latter, the month of August, at which time the crop was heading, was quite favorable.

The average height of the plants in the different years ranges from 3.5 to 6.3 feet. The height depends largely upon the rapidity of growth during the first 30 or 40 days of the vegetative period. When the height of 6.3 feet resulted from the seeding made June 19, 1915, the soil was in a moist condition and remained so for some time, with a temperature favorable for rapid growth. At other times during several of the years when the plants reached a height of less than 4 feet, the crop encountered a long droughty spell during the vegetative period.

TABLE IX.—*Agronomic data for Acme broom corn in the date-of-seeding experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

Date of seeding.	Row space (inches).		Length of period (days).			Percentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Plants.	Stalks.	Vegetative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
Season of 1914:														
May 14	5.8	5.8	73	17	90	0	81.8	4.0	305	60	365	21.0	15.0	80.8
June 1	4.4	4.4	69	22	91	0	68.0	4.3	.....	.....	a612	.....	.....	.....
June 18	5.7	5.7	64	10	74	0	77.9	4.3	.....	.....	a780	.....	.....	.....
Season of 1915:														
May 25	5.5	5.2	77	18	95	4.8	93.0	5.5	600	155	755	23.0	23.0	79.4
June 10	8.6	6.2	78	19	97	28.1	86.7	5.8	750	45	795	22.0	22.0	93.3
June 19	5.6	4.4	80	18	98	20.4	88.2	6.3	875	20	895	20.0	20.0	97.8
July 7	5.9	4.9	69	14	83	15.8	79.2	.....	630	70	700	19.0	19.0	90.0
Season of 1916:														
May 1	5.8	5.5	70	18	88	5.2	89.0	4.8	717	25	742	23.0	14.0	96.6
May 15	6.0	5.2	72	14	86	13.0	70.0	4.5	556	7	563	23.0	19.0	98.9
May 22	8.7	6.6	70	17	87	24.1	83.6	3.8	378	55	433	18.5	16.0	87.2
June 1	5.8	5.5	64	19	83	5.2	83.0	4.0	328	22	350	20.0	13.5	93.7
June 15	5.9	5.1	53	24	77	13.8	91.3	3.8	475	68	543	22.5	18.0	87.4
July 1	5.9	5.4	51	22	73	9.7	79.3	3.8	457	57	514	22.0	19.0	88.9
Season of 1917:														
April 16	6.3	4.9	124	13	137	21.5	83.3	4.0	275	68	343	12.5	11.0	80.0
May 2	6.0	4.6	110	11	121	24.7	86.0	5.0	350	106	456	14.0	12.0	76.7
May 15	5.9	4.9	106	12	118	16.8	90.8	5.0	450	81	531	14.0	12.0	84.7
May 24	7.1	6.5	107	8	115	8.7	97.5	5.5	394	39	433	17.0	13.0	91.0
June 2	6.7	5.9	92	8	100	11.9	92.6	5.5	507	36	543	18.0	15.0	93.4
June 22	7.4	6.1	95	14	109	17.6	83.1	4.5	625	44	669	19.0	15.0	93.5
July 3	10.5	6.1	88	17	105	41.0	75.6	5.0	633	50	683	20.0	14.0	92.7
Season of 1918:														
April 16	27.6	10.3	92	16	108	62.7	91.3	3.8	286	57	343	22.5	18.5	83.3
May 1	22.6	10.2	84	11	95	55.1	80.0	3.5	193	50	243	19.0	16.0	79.4
May 14	39.4	14.6	83	15	98	62.8	90.5	4.5	214	14	228	22.5	15.5	93.8
May 27	7.5	5.8	69	15	84	22.6	66.6	3.5	283	28	311	17.5	15.5	91.1
June 1	7.0	6.6	76	14	90	6.5	60.7	3.5	238	12	250	18.0	12.5	95.0
June 15	5.8	5.4	75	18	93	7.2	84.4	3.5	129	142	271	14.5	11.0	47.4
July 1	8.9	8.3	94	39	133	7.3	76.7	3.8	260	90	350	17.0	11.5	74.3

a Weight of seeded brush before curing.

The yield of good brush, the total yield, the length of the brush, and the percentage of good brush in the total yield vary widely between the different dates of seeding in nearly all years. Good to excellent yields were obtained from one or more of the seedings each year, while those from other seedings were only fair to poor. In 1914 the yield of the cured brush was obtained on one lot only. The other two lots were weighed green after thrashing and accidentally placed on the racks to cure without being properly labeled, which made later identification impossible. The season of 1915 was exceptionally favorable throughout, which resulted in excellent yields from all the dates of seeding. The lowest yield in that year was 700 pounds from the seeding made July 7 and the highest 895 pounds from the seeding of June 19. In the variable season of 1916 the yields ranged from 742 pounds from the May 1 seeding to only 350 pounds from the seeding made on June 1. In 1917 the highest yield was obtained from the seeding made on July 1, the next highest from the June 22 seeding, and the lowest yield from the early seeding, April 16. In 1918, the poorest crop season in the 5-year period, the highest yield, 350 pounds, was from the seeding made July 1, while the lowest, 250 pounds, was made from the June 1 seeding.

COMPARATIVE YIELDS IN THE DATE-OF-SEEDING EXPERIMENTS.

Table X shows the annual and average acre yields of Acme broom corn in the date-of-seeding experiments. The seedings in the different years in some cases were not made on exactly the same date. These dates in some cases varied as much as five days. The resulting yields are considered comparable and in this table are grouped accordingly. Therefore, seedings made on May 22 and 27, on June 10 and 15, and on June 18 and 22 in different years are considered as representing the same dates of seeding.

The annual yields of the good and the poor qualities are shown first. Then is given a 2-year average yield from the plats on all dates used in that period, and then a 3-year average yield for the comparable dates in that period. It will be noted here that the lowest average yield in the 2-year period was from the seedings made on May 1 and that the average yields increased as the date of seeding advanced, reaching the maximum of 446 pounds of good brush from the July 1 seedings. In the 3-year period from 1916 to 1918, inclusive, the highest average yield of good brush, 450 pounds, was obtained from the July 1 seeding, while the second highest, 420 pounds, was from the seedings made on May 1.

These results indicate that the best times to sow are from about May 1 to 15 and from June 15 to July 1. August is usually dry and hot, and such weather has a bad effect on yield and quality of brush if the crop is in the heading stage at that time. This may be avoided by seeding either early or late.

TABLE X.—*Annual and average acre yields of Acme broom corn in date-of-seeding experiments at the Woodward (Okla.) Field Station in the 5-year period from 1914 to 1918, inclusive.*

Date of seeding.	Annual acre yields (pounds).										Average yields.			
	1914		1915		1916		1917		1918		2 years, 1917 and 1918.		3 years, 1916 to 1918.	
	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.
April 16	......	......	......	......	......	......	275	68	286	57	280	62	......	......
May 1 and 2	......	......	......	......	717	25	350	106	193	50	272	78	420	60
May 14 and 15	305	60	......	......	556	7	450	81	214	14	332	47	407	34
May 22 to 27	......	......	600	155	378	55	394	39	283	28	339	33	352	41
June 1 and 2	......	......	......	......	328	22	507	36	238	12	372	24	358	23
June 10 to 15	......	......	750	45	475	68	......	......	129	142	......	......	......	......
June 18 to 22	......	......	875	20	378	55	625	44	......	......	......	......	......	......
July 1 to 7	......	......	630	70	457	57	633	50	260	90	446	70	450	66

RATE-OF-SEEDING EXPERIMENTS.

The rate-of-seeding experiments were conducted with Standard broom corn, C. I. No. 556, and Dwarf broom corn, C. I. No. 557, in the 5-year period from 1914 to 1918, inclusive. Both varieties were sown in each year at three rates, designated as thick, normal, and thin. These rates represent stands of approximately one plant to 4 inches of row space in the thick rates, to 7 inches in the normal rate, and to 10 inches in the thin rate. All rows were spaced 3.5 feet apart. The combined rate-of-seeding and spacing experiments with Acme broom corn, C. I. No. 243, have these same rates included. A discussion of these experiments follows later.

The agronomic data from the rate-of-seeding experiments are shown in Tables XI and XII. It will be seen in Table XI that the stand in each rate of seeding is not exactly the same for both varieties the same year; neither is it the same for each rate in the different years. But the difference in the stands of the varieties in the same rates in any one year is so small that its influence on yields is considered negligible.

The total growing period for the Standard broom corn in the different years ranged from 94 days in 1914, the shortest time required, to 132 days in 1917, the longest. For the Dwarf variety in these same years the time was 91 days and 117 days, respectively, which is 3 days less in the first year mentioned and 15 days less in the second. In each of the other three years the Standard required from 6 to 11 days longer to mature than the Dwarf.

In 1914 neither variety produced suckers. In 1915 none were produced in the thick or the normal rates of the Standard broom corn, but the thin rate produced 9.3 per cent, while in the Dwarf that year the proportion varied from 3.4 per cent in the thick to 26.3 per cent in the thin rate. In 1916 suckers were produced in all rates in both varieties, though the number in the Standard was much smaller than in the Dwarf variety. In 1917 the Standard broom corn produced suckers in all three rates, but in the Dwarf they were present only in the normal and the thin rates. In 1918 there were no suckers in the Standard broom corn sown at the thick rate, but they were present in all three rates in the Dwarf variety. The tendency to sucker is present in both varieties, though to a larger degree in the Dwarf than in the Standard. The development of this tendency is influenced largely by environing condition. Stand is an important factor. Thin stands aid the development of suckers, while thick stands suppress them.

The percentage of stalks headed varies in the plats sown at the different rates in the same year and in the same rates in the different years. This is due in part to seasonal conditions and in part to the number of suckers produced. In the years when suckering was reduced to the minimum, the percentage of headed stalks usually increased as the stand decreased. The reverse is true when the plants sucker profusely. This is so especially when the suckers are late and none of them produce heads. The rates of seeding used in this experiment appear to have had no appreciable effect on the height of the plants.

The highest 5-year yields of good brush of the Standard variety were made in two years at the thick rate of seeding and in two years at the thin rate. The highest total yields of this variety were produced in two years at the thick rate and in three years at the normal rate of seeding. The Dwarf variety made the highest yields of good brush at the thick rate during three years, and in one year each at the normal and thin rates. In total brush produced, the thick rate led in two years and the other two rates each led in one year and tied in another year.

The yield can not be considered the only factor in determining the proper rate of seeding. The length of the brush to be produced is also an important factor. Thick stands tend to produce short brush and thin stands long brush. The fiber may be of good quality but too short to be self-working, or it may be too long to be worked to good advantage without waste in making brooms of average length. Hurl brush that ranges from 18 to 22 inches works to best advantage in the manufacture of parlor and house brooms. Longer brush is required for heavy warehouse and street brooms. Short brush, ranging in length from 12 to 16 inches, is used for insides and for covers to some extent.

The length of the brush varies in most cases with the different rates of seeding in the same year, and it varies according to seasonal conditions with the same rate of seeding in the different years. In the Standard broom corn, the average length of the brush seeded at the thick rate ranged from 15.5 inches in 1918 to 21 inches in 1914, with an average length of 17.9 inches in the 5-year period. The length of the brush from the normal rate ranges from 18.5 inches in 1917 and 1918 to 22 inches in each of the other three years, with an average length of 20.6 inches in the whole period. From the thin rate of seeding the brush length ranges from 18.5 inches in 1918 to 25 inches in 1915 and average 21.5 inches in the entire period.

The length of the brush in the Dwarf variety was influenced by the stand, as it was in the Standard broom corn, but not always to the same extent in the same year. The shortest length produced by this variety from the thick rate was 16.5 inches in 1917 and the longest 21 inches in 1914, with an average of 18.5 inches for the 5-year period. The length of brush seeded at the normal rate ranged from 15.5 inches in 1918 to 22 inches in 1915, with an average of 19.1 inches. From the thin rate the brush length ranged from 17.5 inches in 1917 to 24 inches in 1914 and averaged 19.7 inches for the whole period.

The percentage of good brush in the total brush produced varies with the stand and seasonal conditions. The good brush produced by the Standard variety at the thick rate of seeding ranged from 64.2 per cent of the total in 1914 to 89.4 per cent in 1917, with an average of 77.5 per cent in the 5-year period. The production of good brush from seed sown at the normal rate ranged from 65.2 per cent in 1915 to 91.8 per cent in 1917, and averaged 82.5 per cent in the entire period. At the thin rate the lowest production was 42.7 per cent in 1915 and the highest 89.7 per cent in 1918, with an average of 76.5 per cent.

The Dwarf broom corn produced 68.4 per cent of good brush out of the total yield from the thick rate of seeding in 1914 and 84.6 per cent in 1916, with an average of 79.7 per cent in the 5-year period. From the normal rate of seeding, the lowest proportion, 76 per cent, was produced in 1915, and the highest, 91.4 per cent, in 1918, with an average of 80.8 per cent in the entire period. The lowest proportion of good brush from seed sown at the thin rate was 75.3 per cent in 1917, and the highest was 93.3 per cent in 1918, with an average of 84.7 per cent in the whole period.

From the foregoing data it will be seen that no one rate led in the percentage of good brush produced in all years. The average yield of good brush from different rates of seeding during the whole period indicates which is the most profitable rate of seeding. In the Standard broom corn, the highest average percentage of good brush in the

5-year period was 82.5 per cent, which was produced from the normal rate. In the Dwarf variety, the average production of good brush increased from 79.7 per cent at the thick rate to 84.7 per cent at the thin rate. The average from the normal rate was 80.8 per cent.

TABLE XI.—*Agronomic data for Standard broom corn, C. I. No. 556, and Dwarf broom corn, C. I. No. 557, in rate-of-seeding experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

Year, variety, and rate.	Row space (inches).		Length of period (days).			Pecentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Plants.	Stalks.	Vegetative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
1914, Standard:														
Thick	4.7	4.7	77	17	94	0	65.8	7.0	150	90	240	18.0	13.0	64.2
Normal	6.7	6.7	77	17	94	0	79.6	6.5	225	75	300	22.0	14.0	75.0
Thin	10.7	10.7	77	17	94	0	81.1	7.0	212	69	281	24.0	18.0	75.6
1914, Dwarf:														
Thick	5.1	5.1	73	18	91	0	68.7	4.0	130	60	190	21.0	15.0	68.4
Normal	6.5	6.5	73	18	91	0	77.4	4.0	250	100	350	21.0	14.0	71.4
Thin	8.1	8.1	73	18	91	0	76.1	4.0	300	50	350	24.0	15.0	85.7
1915, Standard:														
Thick	4.2	4.2	80	21	101	0	84.8	8.3	538	118	656	20.0	20.0	81.9
Normal	5.8	5.8	80	21	101	0	94.4	8.3	440	235	675	22.0	22.0	65.2
Thin	9.4	8.6	80	21	101	9.3	78.0	8.3	295	220	515	25.0	25.0	42.7
1915, Dwarf:														
Thick	4.1	3.9	76	19	95	3.4	95.4	5.8	667	133	800	20.0	20.0	83.3
Normal	5.7	5.3	76	19	95	7.0	100.0	5.0	650	205	855	22.0	22.0	76.0
Thin	8.1	6.0	76	19	95	26.3	87.2	5.0	594	150	744	22.0	22.0	79.9
1916, Standard:														
Thick	4.7	4.6	73	18	91	1.1	82.5	6.8	372	78	450	18.0	14.0	82.7
Normal	8.0	7.5	73	18	91	6.6	86.1	7.0	367	38	405	22.0	15.0	90.4
Thin	9.3	8.5	72	19	91	8.4	90.3	6.8	385	40	425	20.0	15.0	90.6
1916, Dwarf:														
Thick	4.7	4.5	70	17	87	2.8	85.4	4.0	440	80	520	18.0	14.0	84.6
Normal	7.6	6.8	70	17	87	10.7	86.9	3.8	361	78	439	20.5	16.0	82.3
Thin	10.0	6.6	70	17	87	34.5	79.9	4.0	420	50	470	19.0	14.5	89.4
1917, Standard:														
Thick	5.1	4.9	112	20	132	3.3	84.3	7.0	380	45	425	18.0	16.5	89.4
Normal	7.0	6.5	112	20	132	6.1	80.8	7.0	350	31	381	18.5	16.5	91.8
Thin	9.8	8.4	108	24	132	14.6	75.3	7.0	260	50	310	20.0	17.5	83.9
1917, Dwarf:														
Thick	4.8	4.8	109	8	117	0	93.5	5.8	390	100	490	16.5	14.0	79.6
Normal	6.8	5.9	109	8	117	12.8	91.3	5.5	378	77	455	15.5	14.0	82.9
Thin	9.5	8.0	109	8	117	15.3	93.2	5.5	305	100	405	16.0	14.0	75.3
1918, Standard:														
Thick	4.0	4.0	78	17	95	0	51.0	5.8	125	55	180	15.5	12.5	69.4
Normal	8.6	6.9	78	17	95	20.3	73.3	6.0	275	30	305	18.5	13.5	90.1
Thin	11.1	7.7	78	17	95	30.4	71.3	6.0	260	30	290	18.5	13.5	89.7
1918, Dwarf:														
Thick	4.5	4.3	69	15	84	5.8	53.2	3.5	215	45	260	17.0	14.0	82.7
Normal	7.2	5.6	69	15	84	21.4	70.4	3.5	294	28	322	16.5	13.5	91.4
Thin	10.8	5.7	69	15	84	47.2	57.8	3.5	280	20	300	17.5	13.5	93.3

COMPARATIVE YIELDS IN THE RATE-OF-SEEDING EXPERIMENTS.

The yield and the quality of the brush are influenced by seasonal conditions. No one rate of seeding, therefore, will prove best in all years. But as the season can not be foretold the rate that gives the highest average yield in a series of years would appear to be the most profitable. Table XII shows the annual and the average acre yields of both good and poor brush by both the Standard and Dwarf broom corn in the 5-year period from 1914 to 1918, inclusive. It may be noted in this table that the highest yield of good brush from the Standard variety in any year was 538 pounds, produced by seeding at the thick rate in 1915, and the lowest yield was 125 pounds, from seed sown at the same rate in 1918. The annual yield from the normal rate of seeding in the five years exceeded that of the other rates in two years only, but the 5-year average yield of this rate is 331 pounds. This is 18 pounds more than the average yield at the thick rate and 49 pounds more than the average yield from the thin rate in the 5-year period. The normal rate of seeding, or a stand of one plant to 6 or 8 inches of row space, appears to be the most profitable rate for a series of years.

From the Dwarf variety the highest annual yield of good brush in the 5-year period was 667 pounds, which was produced by seed sown at the thick rate of 1915. The lowest yield, 130 pounds, was produced at this same rate of seeding in 1914. The normal rate produced a higher yield than either the thick or thin rates in only one year in the 5-year period. However, the normal rate produced a fair yield each year and averaged 387 pounds in the 5-year period. This is 19 pounds more than the average of the seeding at the thick rate and 7 pounds more than the average yield at the thin rate in the 5-year period. From these results it will be seen that in a series of years, including both favorable and unfavorable seasons, the normal rate or a stand providing 6 to 8 inches of row space to the plant is the most profitable rate of seeding and the one that should be used for this variety under similar conditions.

TABLE XII.—*Annual and average acre yields of Standard and Dwarf broom corn in rate-of-seeding experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

Variety and rate.	Annual acre yields (in pounds).										Average yields for the 5 years, 1914 to 1918.	
	1914		1915		1916		1917		1918			
	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.
Standard:												
Thick	150	90	538	118	372	78	380	45	125	55	313	77
Normal	225	75	440	235	367	38	350	31	275	30	331	82
Thin	212	69	295	220	385	40	260	50	260	30	282	82
Dwarf:												
Thick	130	60	667	133	440	80	390	100	215	45	368	84
Normal	250	100	650	205	361	78	378	77	294	28	387	98
Thin	300	50	594	150	420	50	305	100	280	20	380	74

COMBINED RATE-OF-SEEDING AND SPACING EXPERIMENTS.

The combined rate-of-seeding and spacing experiments were conducted with Acme broom corn and consist of different rates of seeding, different numbers of plants in the hills, and different spacing of the rows, either 3.5 or 7 feet apart. The object of these experiments was to determine the reaction of the crop to these different environing conditions. The first section of these experiments consisted of six plats each year during the 5-year period from 1914 to 1918, inclusive, except in 1916, when there were five plats only. The rows in these plats were spaced 3.5 feet apart, with only one plant in each hill, but with the hills spaced at different distances. Each plat each year, therefore, represented a different rate of seeding.

The second section of these experiments consisted of the same number of plats at the same rates each year with the rows spaced the same distance apart (3.5 feet) as in the first part, but each hill contained two plants instead of one. These hills occupied twice as much row space per hill as those in the corresponding rate in the first section of the experiments, so that the space per plant was the same for each plat as for the corresponding plat in the first section.

The third section of these experiments differs from the first and second sections in its duration, in the number of rates of seeding and the spacing represented, and in the grouping of the plants in the hills. The experiments were conducted only during the last three years, 1916 to 1918, inclusive. The plants are grouped four in each hill. The two rates of seeding or of spacing hills employed correspond to two of the rates previously described.

The fourth and last section of these experiments contains the same number of plats sown at the same rates each year as were included in either the first or second section. It differs from them in the spacing of the rows, which are 7 feet apart, and in the hills, which contain one plant only but are twice as thick in the row as in either of the other plats sown at the same rate but with the rows spaced 3.5 feet apart.

ONE PLANT PER HILL, ROWS 3.5 FEET APART.

Table XIII shows the agronomic data obtained from the first section of the rate-of-seeding and spacing experiments. It will be noted in this table that in 1914 the stand varied from 2.8 inches of row space per hill or plant at the thickest rate to 10.5 inches at the thinnest rate. The thickest rate in 1915 was one plant to 3.6 inches of row space and the thinnest rate one plant to 13.5 inches of row space. In 1916 there were five rates only. The thickest rate that year was one plant to 4.5 inches of row space and the thinnest rate 18.1 inches of row space to the plant. Six rates of seeding were used in 1917. The thickest stand in that year was 3 inches of row space to the hill and the thinnest 19.3 inches of row space, with four rates between these extremes. In 1918 the stands from all six rates were identical with those of the previous year.

The rate at which the crop was sown appears to have had no influence on either the vegetative or fruiting periods under normal or favorable growing conditions, such as obtained in the years 1914 and 1915. In these years both periods were the same for all the rates. In the less favorable seasons of 1916, 1917, and 1918 some differences are shown in the length of both the vegetative and fruiting periods. But these differences are not altogether consistent with the rates of seeding. In some cases the plants sown at the thick rates required a longer time in the vegetative period than those at the thinner rates, but in others the reverse is true. This may be due in part to the larger percentage of suckers produced at thin rates. The suckers are later than the main stalks, and if they produce heads, which is not unusual, both the vegetative and fruiting periods may be prolonged.

In 1914 no suckers were produced. In the other years their production at the different rates of seeding increased as the stands decreased, though the percentage in the same rates differed in these years. It was usually highest in the years with seasons most favorable to suckers.

There is no apparent correlation between the percentage of headed stalks and the stand. The percentage of stalks headed varies at the different rates in the same year and at the same rates in the different years, but the variations are not consistent with the rates in either case.

In 1914 the average height of the stalks ranged from 4.3 feet in two of the thicker rates to only 4 feet in the thinner rates. In 1915 the average height, 5.8 feet, was the same in all rates. In 1916 the height of the plants in the thickest and thinnest rates averaged 4 feet only, while the average for two of the intermediate rates was 4.5 feet and 4.3 feet for another rate. In 1917 the stalks averaged highest in the thicker rates and lowest in the intermediate rates, with a noticeable increase in height again in the thinnest rate. The lowest average height, 3.3 feet, in 1918, was in the thickest rate, and the highest average, 4 feet, was in the fifth rate, with a slight decline in the thinnest rate. It appears that the effect of the rate of seeding on the height of the stalks is dependent upon seasonal conditions. When the moisture is sufficient to promote normal growth in the early part of the vegetative period the thick rates produce the taller stalks, and the reverse is true when there is a lack of moisture at that stage of growth.

The yield per acre is shown in pounds: (1) That of good brush, (2) that of poor brush, and (3) the total yield of all brush, which is the combined yields of the good and poor qualities. The yields from sowings at different rates in the same year and from the same rates in different years are not alike, owing primarily to seasonal conditions. It is interesting to note, however, that the highest yield was produced by seedings at the intermediate rates in three years of the 5-year period. The thickest rate outyielded all others in 1917, when there was 7 inches of rainfall in August, and the thinnest rate ranked first in 1918, when the rainfall in August amounted to 0.7 of an inch only. These are the extreme rates of seeding and they can give best results only under extreme seasonal conditions.

The stand has an influence on the length of the brush. Thick stands tend to produce short brush, and thin stands long brush. The difference between the length of the brush produced by the thickest and the thinnest stands in the 5-year period ranges from 6 inches in 1914 to 2 inches in each of the years 1915 and 1917. In 1916 it was 3 inches, and in 1918 there was a difference of 5 inches.

TABLE XIII.—*Agronomic data for Acme broom corn in the combined rate-of-seeding and spacing experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

[One plant in each hill; rows spaced 3.5 feet apart.]

Year.	Row space (inches).		Length of period (days).			Percentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Hills.	Stalks.	Vegetative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
1914	2.8	2.8	73	17	90	0	62.5	4.3	140	100	240	18.0	13.0	58.3
	4.3	4.3	73	17	90	0	66.7	4.3	215	90	305	19.0	15.0	70.5
	5.8	5.8	73	17	90	0	81.8	4.0	305	60	365	21.0	15.0	80.8
	7.7	7.7	73	17	90	0	87.4	4.0	305	20	325	22.0	14.0	93.8
	10.3	10.3	73	17	90	0	67.6	4.0	250	20	270	24.0	17.0	92.6
	10.5	10.5	73	17	90	0	84.2	4.0	280	10	290	24.0	15.0	96.6
1915	3.6	3.6	75	16	91	0	81.4	5.8	683	89	772	22.0	20.0	88.5
	4.8	4.6	75	16	91	4.0	86.9	5.8	775	87	862	23.0	21.0	89.9
	6.3	5.7	75	16	91	8.7	86.1	5.8	685	110	795	23.0	21.0	86.2
	9.4	7.2	75	16	91	24.0	85.5	5.8	590	75	665	25.0	23.0	88.8
	10.9	5.6	75	16	91	48.6	89.2	5.8	735	70	805	23.0	21.0	91.3
	13.5	6.2	75	16	91	54.1	88.4	5.8	650	80	730	24.0	22.0	89.0
1916	4.5	4.3	74	13	87	2.7	79.0	4.0	405	65	470	20.0	15.5	86.2
	6.5	6.0	73	14	87	7.5	90.9	4.5	531	44	575	22.5	18.5	92.4
	9.1	7.4	71	14	85	19.3	90.5	4.5	480	75	555	23.5	18.0	86.5
	12.3	7.8	71	14	85	36.9	89.1	4.3	415	90	505	20.0	16.5	82.2
	18.1	9.3	71	12	83	48.4	86.0	4.0	295	120	415	23.5	16.5	71.1
1917	3.0	2.9	94	26	120	1.6	92.6	5.5	425	105	530	13.5	13.0	80.2
	4.9	4.3	98	22	120	13.1	90.2	5.5	380	125	505	15.5	13.5	75.2
	6.7	5.6	99	18	117	16.3	91.1	5.0	350	90	440	16.5	13.5	79.5
	10.7	6.3	80	29	109	41.5	79.3	4.0	290	55	345	15.5	14.5	84.1
	12.0	6.3	80	28	108	47.5	78.6	4.3	295	55	350	16.0	14.5	84.3
	19.3	8.3	82	35	117	57.3	92.8	4.8	330	65	395	15.5	14.0	82.2
1918	3.1	3.1	76	30	106	0	16.6	3.3	50	33	83	15.5	12.5	60.0
	4.8	4.7	77	20	97	3.1	61.1	3.5	180	34	214	17.5	10.5	83.3
	7.2	6.2	77	20	97	14.6	84.1	3.5	281	38	319	18.0	13.0	88.2
	10.0	7.6	80	17	97	23.8	75.8	3.5	235	25	260	17.5	11.5	90.4
	12.2	7.8	74	10	84	36.1	67.8	4.0	257	43	300	19.5	15.5	85.7
	19.3	8.4	75	9	84	56.4	75.9	3.8	288	37	325	20.5	16.0	88.5

The annual yields of brush are shown in Table XIV, together with 3-year and 5-year averages, so that comparisons may be made readily between the yields from different rates. These same data are shown again in Table XXI with similar data regarding other methods of spacing, for comparison between methods. Those rates which are comparable for at least three years are shown in Table XIV. Rates that did not differ more than 1 inch in row space per hill in the different years are treated as one rate of seeding. The same is true of the 6 to 7 inch and the 9 to 10 inch stands. The 11 to 14 inch stands are grouped as one rate also, though they cover a larger difference (3 inches) in row space per hill.

TABLE XIV.—*Annual and average acre yields of Acme broom corn in the combined rate-of-seeding and spacing experiments at the Woodward (Okla.) Field Station during periods of varying length in the 5-year period from 1914 to 1918, inclusive.*

[One plant in each hill; rows spaced 3.5 feet apart.]

Distance between hills.	Annual acre yields (pounds).										Average yields.			
	1914		1915		1916		1917		1918		3 years, 1916 to 1918.		5 years, 1914 to 1918.	
	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.
4 to 5 inches	215	90	775	87	405	65	380	125	180	34	332	75	391	80
6 to 7 inches	305	60	685	110	531	44	350	90	281	38	387	57	430	68
9 to 10 inches	250	20	590	75	480	75	290	55	235	25	335	52	369	50
11 to 14 inches	280	10	735	70	415	90	295	55	257	43	322	63	396	54
18 to 19 inches					295	120	330	65	288	37	304	74		

The highest annual yield of good brush produced in the 5-year period was 775 pounds from the 4 to 5 inch rate in 1915, and the lowest annual yield was 180 pounds from this same rate in 1918. Here it is seen that the rate which yields highest in a favorable season yields lowest in an unfavorable one. Therefore, the most profitable rate is one that makes fair to good yields each year and a fair average yield in a series of years. The highest average yield in both the 3-year and the 5-year periods was made by the 6 to 7 inch rate. This rate averaged 387 pounds of good brush in the 3-year period from 1916 to 1918, inclusive, or 52 pounds more than its nearest competitor. In the 5-year period, from 1914 to 1918, inclusive, the 6 to 7 inch rate averaged 430 pounds of good brush. The next highest was 396 pounds from the 11 to 14 inch rate, or 34 pounds less.

TWO PLANTS PER HILL, ROWS 3.5 FEET APART.

Table XV shows the agronomic data from rows spaced 3.5 feet apart with plants grouped two in each hill in the rate-of-seeding and spacing experiments. In this second section of the experiments each hill contains two plants instead of one, and the hills occupy twice the row space at the same rate of seeding as they do in the first section. The reaction of the crop under these two methods is quite similar in many ways. While the number of suckers produced increased as the stands decreased, the total percentage of suckers developed under this method is approximately one-third less than developed when the other method of spacing the plants was used. This should tend naturally to increase the percentage of headed stalks, but it is not in proportion to the decrease in the production of suckers. The increase in headed stalks amounts to 5 per cent only, and the decrease in suckers amounts to 35 per cent.

In yield, quality, and length of brush, the reaction of the crop to this method of spacing the hills and plants is quite similar to that of the first method discussed. The response of the crop at the different rates varies with seasonal conditions. The thicker stands usually outyield the other rates in favorable seasons, and the thinner stands give the best results in dry years. At the intermediate rates fair to good yields of good-quality brush are produced in all seasons.

TABLE XV.—*Agronomic data for Acme broom corn in the combined rate-of-seeding and spacing experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

[Two plants in each hill; rows spaced 3.5 feet apart.]

Year.	Row space (inches).		Length of period (days).			Percentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Hills.	Stalks.	Vegatative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
1914	6.6	6.6	73	17	90	0	71.3	4.3	225	60	285	18.0	14.0	79.9
	8.2	8.2	73	17	90	0	75.6	4.3	250	100	350	18.0	15.0	71.4
	11.6	11.6	73	17	90	0	79.6	4.0	275	60	335	20.0	15.0	82.1
	17.8	17.8	73	17	90	0	84.3	4.0	365	20	385	24.0	15.0	95.1
	20.0	20.0	73	17	90	0	83.1	4.0	265	25	295	22.0	16.0	91.4
	23.0	23.0	73	17	90	0	86.1	4.0	340	10	350	24.0	15.0	97.1
1915	7.6	7.6	75	16	91	0	80.8	5.8	710	160	870	21.0	19.0	81.6
	10.6	5.0	75	16	91	6.0	91.7	5.8	735	105	840	22.0	20.0	87.5
	11.6	5.5	75	16	91	4.7	92.8	5.8	670	135	805	22.0	20.0	83.2
	17.0	7.3	75	16	91	14.0	91.4	5.8	600	90	690	24.0	22.0	87.0
	19.4	6.2	75	16	91	36.1	91.7	5.8	695	80	775	24.0	22.0	89.7
	28.0	8.0	75	16	91	43.2	97.1	5.8	580	45	625	26.0	24.0	92.8
1916	9.6	4.7	73	14	87	2.0	85.7	4.3	472	39	511	19.5	13.0	82.6
	13.2	6.0	71	16	87	9.7	89.8	4.5	556	50	606	24.0	22.0	91.7
	18.4	7.8	71	14	85	14.8	91.3	4.5	511	44	555	20.5	18.0	92.0
	25.0	8.8	71	14	85	29.7	92.9	4.3	400	100	500	23.0	17.5	80.0
	33.2	13.6	71	12	83	22.4	92.0	4.3	305	56	361	22.5	19.0	84.6
1917	6.0	6.0	96	24	120	0	87.0	5.5	405	100	505	14.5	12.5	80.2
	9.8	4.4	101	19	120	10.9	92.2	5.0	428	50	478	16.0	13.5	89.5
	13.4	6.0	99	18	117	10.5	92.8	5.5	330	122	422	16.5	13.5	71.1
	21.4	8.3	80	29	109	22.6	85.5	4.0	228	45	273	15.0	13.0	83.7
	23.8	8.5	80	28	108	28.7	88.2	4.0	289	39	328	16.5	14.5	88.1
	41.4	12.5	80	28	108	40.3	89.0	4.0	211	22	233	18.0	15.0	90.5
1918	6.2	6.2	76	30	106	0	21.8	3.5	67	39	106	16.5	13.0	61.6
	9.5	9.3	77	20	97	2.9	65.0	3.5	186	64	250	18.0	13.5	74.3
	14.4	13.6	77	20	97	5.3	86.7	3.8	271	29	300	16.5	11.0	90.5
	19.9	17.3	80	17	97	13.4	78.7	3.5	200	22	222	16.5	10.5	90.0
	24.3	19.5	74	10	84	19.8	82.5	4.0	343	14	357	22.5	18.0	96.0
	36.1	25.1	72	12	84	30.0	87.2	4.0	300	21	321	22.5	17.0	93.0

Table XVI shows both the annual and the average acre yields at the rates of seeding specified in Table XV, so far as they are comparable for either the 3-year period from 1916 to 1918, inclusive, or for the 5-year period from 1914 to 1918, inclusive. The highest annual acre yield of good brush produced at any rate was 710 pounds, which was from the thick rate or a stand of 8 to 10 inches of row space to the hill in 1915. The lowest acre yield, 186 pounds, was produced at this same rate in 1918. The highest average yield in both the 3-year and 5-year periods was produced at the rate of seeding with a stand ranging from 12 to 14 inches of row space to the hill. This is approximately the same rate per acre as one plant to the hill with hills spaced 6 to 7 inches apart in the row, which gave the highest average under the first method discussed. The differences between the 5-year average acre yields given in Table XVI are within the limits of experimental error. For a comparison between the methods, the data contained in Table XVI are repeated in Table XXI.

TABLE XVI.—*Annual and average acre yields of Acme broom corn in the combined rate-of-seeding and spacing experiments at the Woodward (Okla.) Field Station during periods of varying length in the five years from 1914 to 1918, inclusive.*

[Two plants in each hill; rows spaced 3.5 feet apart.]

Distance between hills.	Annual acre yields (pounds).										Average yields.			
	1914		1915		1916		1917		1918		3 years, 1916 to 1918.		5 years, 1914 to 1918.	
	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.
8 to 10 inches.	250	100	710	160	472	39	428	50	186	64	362	51	409	83
12 to 14 inches.	275	60	670	135	556	50	300	122	271	29	376	67	414	79
18 to 21 inches.	365	20	695	80	511	44	228	45	200	22	313	37	400	42
23 to 28 inches.	340	10	580	45	400	100	289	39	343	14	344	51	390	42
33 to 41 inches.	......	......	......	......	305	56	211	22	300	21	272	33	......	......

FOUR PLANTS PER HILL, ROWS 3.5 FEET APART.

Table XVII shows the agronomic data in the third section of the combined rate-of-seeding and spacing experiments, in which the plants were grouped four in each hill in rows spaced 3.5 feet apart. This method of spacing has been in use three years, from 1916 to 1918, inclusive, and only two rates were sown each year. In the first or thick rate, the hills varied in row space from 17.6 inches in 1916 to 19.6 inches in 1917. This rate represents approximately the same number of plants per acre as the rate with one plant each in hills spaced from 4 to 5 inches apart in the row, which was considered under the first method of spacing used in these experiments. The second or thinner rate in this method required a row space per hill varying from 26.8 inches in 1917 to 28.8 inches in 1918, which is equivalent to one plant each in hills spaced approximately 7 inches apart in the row.

TABLE XVII.—*Agronomic data for Acme broom corn in the combined rate-of-seeding and spacing experiments at the Woodward (Okla.) Field Station during the 3-year period from 1916 to 1918, inclusive.*

[Four plants in each hill; rows spaced 3.5 feet apart.]

Year.	Row space (inches).		Length of period (days).			Percentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Hills.	Stalks.	Vegetative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
1916	17.6	4.1	73	14	87	6.3	87.7	4.3	525	65	590	20.0	17.5	89.0
	28.4	6.4	71	16	87	9.9	90.2	4.5	480	50	530	23.0	18.5	90.6
1917	19.6	4.7	99	21	120	4.0	94.0	5.3	469	25	494	15.5	12.0	94.9
	26.8	6.5	95	21	116	3.5	96.7	5.0	372	72	444	16.5	13.5	83.8
1918	19.1	18.9	77	20	97	1.6	75.3	3.8	256	38	294	15.5	10.5	87.2
	28.8	28.4	75	22	97	1.3	85.3	3.5	242	29	271	18.0	12.5	89.5

The reaction of the crop to this method of grouping the plants appears to be about the same as to the other methods previously considered with regard to the vegetative, fruiting, and total growing periods. A small percentage of suckers was produced at both rates each year, but the average percentage in either rate is much smaller than that of the corresponding rates with single plants in each hill; at the thinner rate a higher percentage of headed stalks was produced each year than at the thick rate, but the highest yield of both good brush and total brush was obtained at the thick rate in all three years. The thinner rate produced the longest average length of brush each year. The annual and 3-year average acre yields are shown in Table XVIII, where comparisons are readily made between these two rates, and these same data are shown again in Table XXI, where comparisons with other methods of spacing are made.

TABLE XVIII.—*Annual and average acre yields of Acme broom corn in the combined rate-of-seeding and spacing experiments at the Woodward (Okla.) Field Station during the 3-year period from 1916 to 1918, inclusive.*

[Four plants in each hill; rows spaced 3.5 feet apart.]

Distance between hills.	Annual acre yields (pounds).						Average yields for the 3 years 1916 to 1918.	
	1916		1917		1918			
	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.
17.6 to 19.6 inches	525	65	469	25	256	38	417	42
26.8 to 28.8 inches	480	50	372	72	242	29	365	50

ONE PLANT PER HILL, ROWS 7 FEET APART.

Table XIX shows the agronomic data from the fourth section of the rate-of-seeding and spacing experiments, in which the hills contained one plant each and the rows were spaced 7 feet apart. This method has been used in the 5-year period from 1914 to 1918, inclusive. It contained six rates of seeding each year except in 1915, when there were only five rates. These rates in most cases are directly comparable with those in the first and second methods considered and shown in Tables XIII and XV, respectively. The total number of plants to the acre is approximately the same at any given rate in all three methods, but they are grouped differently in the rows. In this fourth method the plants stand twice as thick in the rows, but the rows are twice as far apart.

In 1914 the sowings at the six rates presented stands varying in row space per hill or plant from 2.1 inches at the thickest rate to 6.3 inches at the thinnest rate. This was a difference of 4.2 inches of row space per hill between the extreme rates. In 1915 the thickest rate had 2.8 inches of row space to the hill and the thinnest rate 8.1 inches, which was a difference of 5.5 inches between these extremes. There were five rates only in 1915. These represent the extreme rates used in the previous year, but omit one of the intermediate rates. The six rates used in 1917 and in 1918 are approximately the same.

The crop shows no effect on growth on account of the different rates of seeding in this method of spacing the rows under normal seasonal conditions, such as existed in 1914 and 1915. In unfavorable dry seasons, growth was slower at the thick rates than at the thinner ones, which prolongs the vegetative and total growing periods. This was the case in 1917 and 1918, when more time was required to mature by the crop sown at the thick rates than at the thin rates.

The influence the stand has on the production of suckers is illustrated again by this method of spacing the rows and plants. It appears that a stand of about 2 inches of row space to the plant practically eliminates suckering, even in years when conditions are favorable to their growth. The percentage of suckers increases as the stand decreases in all the methods of spacing the plants.

The thin rates in rows spaced 7 feet apart developed a much larger percentage of suckers than was developed in rows spaced 3.5 feet apart having the same number of plants in the row. The stand with 6 inches of row space to the plant in rows spaced 7 feet apart produced an average of 18.3 per cent of suckers in the 4-year period from 1915 to 1918, inclusive, while the 6-inch stand in the rows spaced 3.5 feet apart produced an average of 11.8 per cent. The 9-inch stand in the rows spaced 7 feet apart produced an average of 37.7

per cent of suckers, and in the rows spaced 3.5 feet apart the average was only 27.1 per cent during the same period. However, when the same numbers of plants to the acre are grown in rows spaced 3.5 feet apart and in rows spaced 7 feet apart, the percentage of suckers developed in the rows 3.5 feet apart is materially larger than in the rows 7 feet apart, in which there are twice as many plants to the row. The comparison is made quickly by dividing by 2 the first percentage in each pair given above.

The average percentage of stalks headed is slightly higher in this case than when the method of spacing the rows 3.5 feet apart was used. The height of the plants also averages greater in most of the years when the rows are spaced 7 feet apart.

TABLE XIX.—*Agronomic data for Acme broom corn in the combined rate-of-seeding and spacing experiments at the Woodward (Okla.) Field Station during the 5-year period from 1914 to 1918, inclusive.*

[One plant in each hill; rows spaced 7 feet apart.]

Year.	Row space (inches).		Length of period (days).			Percentage of—		Height of plants (feet).	Yield of brush per acre (pounds).			Length of brush (inches).		Percentage of good brush.
	Hills.	Stalks.	Vegetative.	Fruiting.	Total.	Suckers.	Headed stalks.		Good.	Poor.	Total.	Good.	Poor.	
1914	2.1	2.1	73	17	90	0	74.8	4.5	155	130	285	18.0	15.0	53.7
	2.8	2.8	73	17	90	0	81.0	4.5	275	30	305	20.0	15.0	90.2
	3.2	3.2	73	17	90	0	78.5	4.3	250	30	280	20.0	15.0	89.3
	3.8	3.8	73	17	90	0	81.5	4.3	205	40	245	20.0	15.0	83.7
	4.9	4.9	73	17	90	0	88.0	4.3	225	25	250	23.0	15.0	90.0
	6.3	6.3	73	17	90	0	94.2	4.3	310	15	325	24.0	17.0	95.4
1915	2.8	2.8	75	16	91	0	90.1	5.8	570	85	655	20.0	18.0	87.0
	3.7	3.7	75	16	91	0	96.7	5.8	530	80	610	23.0	21.0	86.9
	5.2	5.2	75	16	91	0	90.0	5.8	390	50	440	24.0	22.0	88.6
	5.4	5.3	75	16	91	1.5	91.6	5.8	485	60	545	24.0	22.0	89.0
	6.3	5.4	75	16	91	14.4	99.4	5.8	463	37	500	25.0	23.0	92.5
	8.1	5.1	75	16	91	36.7	93.1	5.8	465	25	490	26.0	24.0	94.9
1916	2.6	2.6	73	14	87	0	84.7	5.0	456	38	494	20.5	14.5	92.4
	3.7	3.6	71	16	87	2.1	91.4	4.8	438	50	488	23.0	18.5	89.7
	4.6	4.3	71	14	85	4.8	91.6	5.0	400	44	444	23.0	16.0	90.1
	6.4	5.1	71	14	85	20.0	93.9	4.8	363	75	438	25.5	16.5	82.9
	9.2	5.7	71	12	83	38.0	91.0	4.8	300	87	387	24.0	16.5	80.0
1917	1.5	1.5	96	24	120	0	73.6	5.5	130	210	340	15.0	13.0	38.2
	2.5	2.4	94	26	120	1.0	92.4	5.5	325	81	406	16.0	13.5	80.0
	3.4	3.2	87	29	116	5.0	94.2	5.5	312	106	418	17.0	14.0	74.6
	5.4	4.8	78	31	109	10.4	93.1	4.5	244	50	294	16.0	12.5	83.0
	6.0	4.8	78	30	108	20.5	87.1	4.5	231	32	263	15.0	13.0	88.1
	9.7	5.3	78	30	108	45.0	82.9	4.5	220	25	245	17.5	15.0	89.8
1918	1.6	1.6	80	17	97	0	78.2	3.8	155	110	265	17.0	11.5	58.5
	3.1	3.1	73	11	84	0	72.0	4.3	294	37	331	20.0	15.0	88.7
	3.6	3.6	73	11	84	0	67.4	4.3	238	37	275	20.5	14.5	86.4
	5.0	4.6	73	15	88	8.3	75.2	4.0	134	41	175	19.0	15.5	76.8
	6.0	4.9	73	11	84	18.4	80.6	4.5	325	25	350	21.0	16.5	92.9
	9.2	6.3	75	9	84	31.2	78.0	4.3	256	13	269	21.5	16.5	95.4

The reaction of the crop, as shown by yield of brush with this method of spacing, is quite similar to that in the case of the methods already discussed. Under favorable growing conditions the thicker rates give the highest yields, and in less favorable and poor seasons the thinner stands outyield the others. It is necessary, therefore, to study the average yields for a period of years in order to determine the most profitable rate of seeding and spacing.

The annual and average acre yields are shown in Table XX. It will be noted in this table that rates which show a slight variation in row space per hill in the different years are considered comparable and treated as a single rate. Five rates are presented here. The lowest annual acre yield of good brush was 134 pounds, made at the 4 to 5 inch rate in 1918, and the highest yield was 570 pounds, made with the 2 to 3 inch spacing in 1915. This spacing made the best yield in four out of the five years and gave the highest average in both the 3-year and the 5-year periods. The next highest average in both these periods was from the spacing varying from 3.4 to 3.8 inches. The lowest 5-year average yield was with the 4 to 5 inch spacing, and this rate tied with the 8 to 10 inch spacing for low yield in the 3-year period.

TABLE XX.—*Annual and average acre yields of Acme broom corn in the combined rate-of-seeding and spacing experiments at the Woodward (Okla.) Field Station during periods of varying length in the five years from 1914 to 1918, inclusive.*

[One plant in each hill; rows spaced 7 feet apart.]

Distance between hills.	Annual acre yield (pounds).										Average yield.			
	1914		1915		1916		1917		1918		3 years, 1916 to 1918.		5 years, 1914 to 1918.	
	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.
2 to 3 inches...	275	30	570	85	456	38	325	81	294	37	358	52	384	54
3.4 to 3.8 inches	205	40	530	80	438	50	312	106	238	37	329	64	345	63
4.6 to 5.4 inches	225	25	390	50	400	44	244	50	134	41	259	45	279	42
6 to 6.4 inches.	310	15	463	37	363	75	231	32	325	25	306	44	338	37
8 to 10 inches..	......	......	465	25	300	87	220	25	256	13	259	32	......	......

COMPARATIVE YIELDS FROM ALL METHODS OF SPACING.

In Table XXI all comparable rates of seeding in the different methods of spacing used in these experiments are presented, so that comparisons may be made easily between the annual and average acre yields from all methods of spacing. Five different rates are represented here, and these are distributed into five groups, each one containing different combinations having the same number of plants per acre. Data given for each group are the distance between the rows in feet, the row space to the hill in inches, the number of plants in each hill, and the annual and average acre yield for each method of spacing.

Group A contains the data for the thick rate in each method of spacing. This rate represents an average of approximately one plant to 4.5 inches of row space in rows 3.5 feet apart and of one plant to each 2 or 3 inches where the rows were 7 feet apart, or 35,200 plants to the acre. The highest annual yield of good brush, 775 pounds, at this rate was made in 1915, by method 1, with rows spaced 3.5 feet apart and one plant in each hill. This method also made the lowest yield, 180 pounds, in 1918. It has the lowest average yield in the 3-year period from 1916 to 1918, inclusive, and ranks second in the 5-year period from 1914 to 1918, inclusive. The highest average yield in the 3-year period was obtained by the use of the method of grouping four plants in each hill in rows 3.5 feet apart. This method was employed only during that period. The method of spacing the rows 7 feet apart with one plant in each hill gave the highest annual yield in 1914 and in 1918, but it ranks third in average yield in both the 3-year and the 5-year periods.

Group B represents an average of one plant to 6.5 inches of row space where the rows were 3.5 feet apart or half as many inches where the rows were 7 feet apart, or 24,400 plants to the acre. In this rate the first method, spacing one plant in a hill in rows 3.5 feet apart, gave the highest annual yield in three years of the 5-year period and in average yield ranks first in both the 3-year and the 5-year periods. The second method, with two plants in the hill, made the highest yield in only one year, 1916, but it ranks second in average yield in both periods. By the fourth method, or spacing the rows 7 feet apart, much lower yields were made than by any of the others in nearly all years, which gave it a low rank in both periods.

Group C represents a stand of one plant to 9.5 inches of row space in 3.5-foot rows or about 5 inches in rows 7 feet apart, or 16,700 plants to the acre. At this rate, the crop grown in rows spaced 3.5 feet apart gave a much higher yield than when grown in rows spaced 7 feet apart. The second method, or grouping two plants in the hill, gave the highest yield in two years of the 5-year period. This gave the first method the highest average in the 3-year period from 1916 to 1918, inclusive, and the second method the highest average in the 5-year period from 1914 to 1918, inclusive.

Group D has a stand of 12.5 inches of row space to the hill or its equivalent in 7-foot rows, or 12,600 plants to the acre. At this rate, as in the previous one, the crop grown in rows spaced 3.5 apart gave a higher yield than when grown in rows spaced 7 feet apart. The first method, with one plant in the hill, gave the highest yield in three years and ranks first in the 5-year average. The second method, with two plants in the hill, produced the highest yield in two years in the 5-year period and ranks first in the 3-year average.

Group E has an average of 18.5 inches of row space to the plant or its equivalent in 7-foot rows, or 8,500 plants to the acre. This rate was in use only three years, from 1916 to 1918, inclusive. In that time the first method of spacing, with one plant in each hill in rows spaced 3.5 feet apart, gave the highest yield in one year only; but its average yield in the 3-year period exceeded that of any of the other methods in use.

TABLE XXI.—*Annual and average acre yields of Acme broom corn in the combined rate-of-seeding and spacing experiments at Woodward (Okla.) Field Station in most or all of the five years from 1914 to 1918, inclusive, showing the results obtained at all rates of seeding in all methods of spacing, arranged in five groups, each containing rates having the same number of plants per acre.*

Distance between rows.	Hills.		Annual acre yields (pounds).										Average yields.			
	Spacing (inches).	Plants.	1914		1915		1916		1917		1918		3 years, 1916 to 1918.		5 years, 1914 to 1918.	
			Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.	Good.	Poor.
Group A.—AVERAGE OF 1 PLANT TO 4.5 INCHES OF ROW SPACE, OR 35,200 PLANTS TO THE ACRE.																
3.5 feet	4 to 5	1	215	90	775	87	405	65	380	125	180	34	322	75	391	80
3.5 feet	8 to 10	2	250	100	710	160	472	39	428	50	186	64	362	51	409	83
3.5 feet	17.6 to 19.6	4	.....	....	.....	.....	525	65	469	25	256	38	417	42	.....	....
7 feet	2 to 3	1	275	30	570	85	456	38	325	81	294	37	358	52	384	54
Group B.—AVERAGE OF 1 PLANT TO 6.5 INCHES OF ROW SPACE, OR 24,400 PLANTS TO THE ACRE.																
3.5 feet	6 to 7	1	305	60	685	110	531	44	350	90	281	38	387	57	430	68
3.5 feet	12 to 14	2	275	60	670	135	557	50	300	122	271	29	376	67	414	79
3.5 feet	26.8 to 28.8	4	.....	....	.....	.....	480	50	372	72	242	29	365	50	.....	....
7 feet	3.4 to 3.8	1	205	40	530	80	438	50	312	106	238	37	329	64	345	63
Group C.—AVERAGE OF 1 PLANT TO 9.5 INCHES OF ROW SPACE, OR 16,700 PLANTS TO THE ACRE.																
3.5 feet	9 to 10	1	250	20	590	75	480	75	290	55	235	25	335	52	369	50
3.5 feet	18 to 21	2	365	20	695	80	511	44	228	45	200	22	313	37	400	42
7 feet	4.6 to 5.4	1	225	25	390	50	400	44	244	50	134	41	259	45	279	42
Group D.—AVERAGE OF 1 PLANT TO 12.5 INCHES OF ROW SPACE, OR 12,600 PLANTS TO THE ACRE.																
3.5 feet	11 to 14	1	280	10	735	70	415	90	295	55	257	43	322	63	396	54
3.5 feet	23 to 28	2	340	10	580	45	400	100	289	39	343	14	344	51	390	42
7 feet	6 to 6.4	1	310	15	463	37	363	75	231	32	325	25	306	44	338	37
Group E.—AVERAGE OF 1 PLANT TO 18.5 INCHES OF ROW SPACE, OR 8,500 PLANTS TO THE ACRE.																
3.5 feet	18 to 19	1	.....	....	.....	.....	295	120	330	65	288	37	304	74	.....	....
3.5 feet	33 to 41	2	.....	....	.....	.....	305	56	211	22	300	21	272	33	.....	....
7 feet	8 to 10	1	.....	....	465	25	300	87	220	25	256	13	259	32	.....	....

In summing up the results from the rate-of-seeding and spacing experiments, it is interesting to note that the crop grown in rows spaced 3.5 feet apart gave the highest average yield in all five groups or rates in both the 3-year and the 5-year periods. The first method, with one plant in each hill in rows spaced 3.5 feet apart, gave the highest average yield in groups B, C, and E, or in three of the five rates in the 3-year period. This method ranked first in groups B and D, or in two of the four rates averaged in the 5-year period. The third method, with four plants in each hill, gave the highest average in group A, or the thick rate, in the 3-year period. The second method, with two plants in the hill, gave the highest average in group D in the 3-year and in groups A and C in the 5-year period. Thus, it is seen that the first method, with one plant in the hill in rows spaced 3.5 feet apart, has more high averages than any other method. This is a good indication that it is the most favorable method of spacing, and also from 6 to 7 inches of row space to the plant appears to be the most profitable rate of seeding, as that is the rate which gave the highest average yield in this experiment and in all other experiments as well.

HARVESTING EXPERIMENTS.

The object of the harvesting experiments was to learn the stage of development at which broom corn should be harvested to obtain the highest yield and quality of cured brush. The experiments were conducted in the seasons of 1915, 1917, and 1918. Acme broom corn (C. I. No. 243) was used in making these experiments.

In 1915 the harvesting experiment was conducted to learn the stage of maturity at which to harvest broom corn to obtain the highest yield of cured brush. Three plats of broom corn, not equal in area, in different stages of development, were harvested. The first lot was in the flower stage, the second in the milk, and the third lot in the dough stage when harvested. Each lot was weighed as soon as harvested, including the seed. Then the heads were thrashed and the brush was put on racks in the shed to cure. After the brush was thoroughly dry the cured weights were obtained.

TABLE XXII.—*Data obtained from the broom-corn harvesting experiment conducted at Woodward, Okla., in 1915.*

Stage of development.	Green brush, including seed.	Cured brush.	Cured brush.
	Pounds.	*Pounds.*	*Per cent.*
Flower	309	79	25.6
Milk	209	59	28.2
Dough	441	142	32.2

The data in Table XXII show that 309 pounds of broom corn harvested in the flower stage yielded 79 pounds of cured brush, which is 25.6 per cent of the total green weight. When harvested in the milk stage, 209 pounds produced 59 pounds of cured brush, or 28.2 per cent of the total green weight. In the dough stage 441 pounds, green weight, produced 142 pounds, or 32.2 per cent of cured brush. From these data it is apparent that broom corn harvested in the dough stage gives a higher percentage of cured brush than when it is harvested at either the flower or milk stage. To obtain the highest yield of cured brush, therefore, broom corn should be allowed to reach the dough stage before it is harvested.

In 1917 the harvesting experiment was conducted on an area of 0.36 of an acre, which was divided into three equal and uniform portions. The broom corn was harvested from one portion of that area in the flower stage, from another in the milk, and from the third portion in the dough stage. Owing to unfavorable growing conditions the crop was nonuniform in heading, which made necessary several successive harvestings to get the heads as they reached the desired stages of maturity. Counts were made of the heads when harvested. Then they were thrashed and put on shelves in the shed to cure. After the brush was cured the dry weights were obtained. From these weights the number of heads to the pound of cured brush was determined for each stage, as shown in Table XXIII.

In 1918 broom corn was harvested at two stages only. Unfavorable climatic conditions prevailed at heading time, which made head development slow and nonuniform, and no harvesting was done at the flower stage. Later, heads were harvested in both the milk and dough stages of development. These lots were harvested on the same day and from the same rows of broom corn, as both stages were present at the same time. After harvest the experiment was conducted the same as in 1917. The 1918 results are shown in Table XXIII.

The results from the experiment in all three years tend to show rather conclusively that the highest yield of cured brush will be obtained when harvest is delayed until the seeds are in the dough stage.

TABLE XXIII.—*Data from the broom-corn harvesting experiments conducted at the Woodward (Okla.) Field Station in the seasons of 1917 and 1918.*

Year and stage of development.	Heads harvested.	Cured brush.	
		Total.	Heads per pound.
	Number.	*Pounds.*	*Number.*
Season of 1917:			
Flower	3,549	53.0	67.0
Milk	3,472	60.5	57.4
Dough	3,200	58.5	54.7
Season of 1918:			
Milk	811	18.3	44.3
Dough	546	15.6	35.0

WEARING QUALITY OF THE BRUSH.

Brooms were made from the lots of brush harvested at the different stages of maturity in 1917 and 1918, in order to test the wearing quality of the brush. These brooms were divided into sets and are being used for sweeping both private dwellings and office buildings. Each set contains one broom made of brush harvested at the different stages of maturity.

This part of the harvesting experiment has not progressed far enough as yet to draw final conclusions. However, the indications are that the brush harvested in the dough stage will give the best service. When harvested at the earlier stages, the fibers are too weak at the base to stand hard usage. They break over the shoulders of the broom.

NURSERY EXPERIMENTS.

The objects of the broom-corn nursery were to learn the quality of the seed from commercial sources and to obtain stock for subsequent breeding. In the spring of 1915 thirty-four lots of broom-corn seed were obtained from commercial sources and a row 132 feet long was sown with each lot of seed. Nearly all lots of seed were received under some varietal name which indicated whether the seed was of the Standard or of the Dwarf variety. In a few cases the names were misleading, as the same name was applied to both varieties. In other cases the word Dwarf was part of the name used for the Standard variety, or Standard was used in combination with other words for the Dwarf variety. Each lot of seed was given a Cereal Investigations number (C. I. No.).

The commercial name, Cereal Investigations number, and source of all the lots of broom corn grown in the nursery in part or all of the four years from 1915 to 1918, inclusive, are shown in Table XXIV. It will be noted in this table that the seed came from 14 different States and from several different localities in some of these States. One lot came from France, one from Germany, and one from the Greek exhibit at the Panama-Pacific Exposition.

HEIGHT OF PLANTS AND DURATION OF VEGETATIVE PERIOD.

Table XXV shows the height of the plants (in feet) and the duration of the vegetative period (in days) for all lots of broom corn grown in the nursery in part or in all of the years from 1915 to 1918, inclusive, with 4-year averages. The height of Standard broom corn ranged from 7 to 11 feet in 1915. In the less favorable seasons of 1916, 1917, and 1918 the plants averaged much lower in height than in the favorable season of 1915. Dwarf broom corn reached a height of 5 to 6 feet in 1915, but in 1918 the height ranged from 2.8 to 4.3 feet only.

TABLE XXIV.—*Commercial names, Cereal Investigations numbers, and sources of the different lots of broom corn grown in the nursery at the Woodward (Okla.) Field Station in part or all of the four years from 1915 to 1918, inclusive.*

Commercial name.	C. I. No.	Source.
Standard:		
Standard broom corn	446	Oakland, Ill.
Do	556	Linsday, Okla.
Do	560	Paris, France.
European sorghum	561	Sherman, Tex.
Broom corn	563	Springfield, Mo.
Standard Evergreen	565	Houston, Tex.
California Golden Dwarf	580	Do.
California Golden	582	Lawrence, Kans.
Improved Evergreen	583	Dallas, Tex.
Do	584	Ravenna, Ohio.
Do	585	Richmond, Va.
Do	586	Lawrence, Kans.
Tennessee Evergreen	587	Do.
Evergreen	588	New York, N. Y.
Do	589	Des Moines, Iowa.
Do	590	Chicago, Ill.
Missouri Evergreen	591	Kansas City, Mo.
Longbrush Evergreen	592	New York, N. Y.
Evergreen	593	Milwaukee, Wis.
Do	594	Birmingham, Ala.
Mammoth Dwarf	600	Wichita, Kans.
Improved Evergreen	602	Denver, Colo.
Evergreen	603	Lincoln, Nebr.
Dwarf Evergreen	604	Los Angeles, Calif.
Broom corn	607	Greek Exhibit, Panama-Pacific Exposition.
Dwarf.		
Acme	243	Amarillo, Tex.
Whisk Dwarf	442	Sterling, Kans.
Dwarf broom corn	535	Amarillo, Tex.
Evergreen Dwarf	557	Elk City, Okla.
Dwarf broom corn	558	Carignan, Ardennes, France.
Do	559	Erfurt, Germany.
European sorghum	562	Sherman, Tex.
Standard Evergreen	564	Wichita, Kans.
California Golden	581	Des Moines, Iowa.
Oklahoma Dwarf	595	Lawrence, Kans.
Do	596	Kansas City, Mo.
Dwarf	597	Dallas, Tex.
Do	598	Des Moines, Iowa.
Do	599	New York, N. Y.
Do	601	Denver, Colo.
Broom corn	605	Bard, Calif.
Do	606	Do.

The duration of the vegetative period with Standard broom corn shows a difference of 20 days between the earliest and latest maturing lots in 1915, which increased to 34 days in 1918. The variation in the vegetative period between the different lots of Dwarf broom corn was 19 days in 1915, which was increased to 44 days in 1918.

ROW SPACE AND PERCENTAGE OF SUCKERS.

The row space per plant in inches and the percentage of suckers, of stalks headed, and of good heads, with 2-year averages, for each lot of broom corn grown in the nursery during the two years 1917 and 1918 are shown in Table XXVI. It will be noted that a uniform stand of about 7 inches of row space to the plant was obtained in nearly all the lots in 1917, and that, with a few exceptions, the same uniformity existed in the stand in 1918.

TABLE XXV.—*Height and duration of vegetative period with 4-year averages for each lot of broom corn grown in the nursery at Woodward (Okla.) Field Station during the 4-year period from 1915 to 1918, inclusive.*

Variety and lot (C. I. No.).	Height (feet).				4-year average, 1915 to 1918.	Growing period (days).[1]				4-year average, 1915 to 1918.
	1915	1916	1917	1918		1915	1916	1917	1918	
Standard:										
446	9.0	7.0	7.0	6.0	7.3	83	72	100	77	83
556	......	7.5	6.5	6.3	......	......	71	101	80	......
560	10.0	6.8	7.5	5.5	7.5	93	81	112	88	93
561	11.0	7.0	8.0	7.3	8.3	96	86	114	98	98
563	11.0	6.5	8.0	6.5	8.0	93	87	116	106	100
565	10.0	7.0	6.5	5.8	7.3	82	76	105	85	87
580	9.0	6.5	6.0	5.5	6.8	79	68	89	70	77
580-2	......	......	6.0	......	......	......	......	89	......	......
582	9.0	7.0	6.0	......	......	79	70	105	......	......
582-2	......	7.0	6.0	5.5	6.9	......	68	105	75	82
583	9.0	8.0	6.5	6.3	7.5	77	73	94	77	80
584	10.0	7.5	7.0	6.0	7.9	81	81	112	94	92
585	10.0	7.3	7.0	......	......	79	76	104	......	......
586	9.0	......	......	......	......	88	......	......	......	......
587	9.0	8.0	8.0	......	......	77	83	112	......	......
588	8.0	7.5	6.0	......	......	77	70	94	......	......
589	9.0	8.0	8.0	......	......	80	76	112	......	......
590	7.5	......	......	......	......	76	......	......	......	......
591	8.0	7.5	7.0	6.0	7.1	76	70	105	80	83
592	8.0	8.0	7.0	......	......	77	69	104	......	......
593	8.0	7.5	6.5	6.0	7.0	77	76	97	85	84
594	8.0	8.0	7.0	6.3	7.3	77	74	100	78	82
600	8.0	8.0	7.0	......	......	81	72	104	......	......
602	8.0	8.0	6.0	7.0	7.3	77	70	94	77	79
603	7.5	......	......	......	......	76	......	......	......	......
604	11.0	7.5	7.0	6.5	8.0	76	83	112	89	95
607	......	7.0	6.0	......	......	......	71	109	......	......
Dwarf:										
243	......	4.8	5.0	3.5	......	......	71	93	74	......
442	......	3.3	3.5	2.8	......	......	76	94	73	......
535	......	5.0	5.0	3.5	......	......	70	91	73	......
557	......	5.3	5.0	3.5	......	......	70	96	74	......
558	5.0	4.8	5.5	4.3	4.9	96	93	111	109	102
559	5.0	5.0	5.5	4.0	4.9	96	87	115	108	102
562	6.5	......	......	......	......	76	......	......	......	......
564	6.0	5.3	4.8	3.8	5.0	83	70	102	72	82
581	5.3	......	......	......	......	80	......	......	......	......
595	6.0	5.0	4.5	3.3	4.7	81	69	95	72	79
596	5.5	5.0	4.5	3.5	4.6	80	63	93	75	79
597	6.0	5.5	4.5	3.5	4.9	84	70	105	72	83
598	6.0	5.5	5.0	3.5	5.0	81	74	105	74	84
599	6.0	5.5	5.0	3.5	5.0	81	76	112	75	86
601	5.8	......	......	......	......	77	......	......	......	......
605	......	5.0	5.5	4.0	......	......	91	114	116	......
606	......	4.5	5.5	......	......	......	93	119	......	......

[1] The vegetative period extends from the date of seeding to the date when heads apparently cease to appear.

The tendency to sucker is present in both the Standard and Dwarf varieties, but to a much greater degree in some lots than in others. The percentage of suckers in most of the lots did not vary greatly in the two years recorded. However, a few lots in each variety show a wide variation. Standard broom corn (C. I. No. 580) developed 34.3 per cent of suckers in 1917 and only 5.5 per cent in 1918. The highest percentage of suckers developed in Dwarf broom corn was 46.3 per cent by C. I. No. 595 in 1917. This same lot produced only 30.1 per cent in 1918.

PERCENTAGE OF HEADS AND QUALITY OF BRUSH.

In 1917 the Standard broom corn grown in the nursery ranged in the proportion of stalks headed from 73.5 per cent for C. I. No. 580 to 93.4 per cent for C. I. No. 561, with an average of about 74 per cent for all lots. The percentage of good brush that year was quite low, ranging from less than 1 per cent in several lots to as high as 24.4 per cent in one lot only. Good brush as considered in this experiment includes those heads which have uniformly long, round fiber full and even at the tip and evenly attached to the peduncle at the base. These heads are suitable for the improvement of the strain. In 1918 there was a slight increase in the percentage of good brush over that of the previous year, as shown in Table XXVI.

TABLE XXVI.—*Row space per plant, the percentage of suckers, of headed stalks, and of good heads for each lot of broom corn grown in the nursery at the Woodward (Okla.) Field Station during the two years 1917 and 1918, with the 2-year averages.*

Variety and lot (C. I. No.).	Row space per plant (inches).			Suckers (per cent).			Percentage of stalks headed.			Percentage of good heads.[1]		
	1917	1918	2-year average, 1917 and 1918.	1917	1918	2-year average, 1917 and 1918.	1917	1918	2-year average, 1917 and 1918.	1917	1918	2-year average, 1917 and 1918.
Standard:												
446	7.6	7.1	7.4	6.7	5.1	5.9	85.6	86.0	85.8	7.8	87.1	47.5
556	6.8	6.8	6.8	6.8	5.3	6.1	81.5	83.4	82.5	6.4	87.8	47.1
560	7.3	6.4	6.9	5.2	9.5	7.4	89.0	58.1	73.6	3.9	94.3	49.1
561	7.0	12.2	9.6	7.7	17.7	12.7	93.4	55.0	74.2	24.4	95.4	59.9
563	8.4	8.0	8.2	6.9	7.0	7.0	90.1	55.6	72.9	21.8	71.4	46.6
565	7.0	6.8	6.9	9.3	6.4	7.9	87.1	80.2	83.7	6.0	81.5	43.8
580	7.9	6.6	7.3	34.3	5.5	19.9	73.5	90.1	81.8	3.1	78.1	40.6
580-2	8.0	......	......	29.3	......	......	74.6	......	......	4.3	......	......
582	6.7	......	......	4.4	......	......	89.8	......	......	......	......	......
582-2	7.3	7.8	7.6	16.9	15.1	16.0	82.3	84.8	83.6	3.2	79.2	41.2
583	8.0	12.9	10.5	30.9	12.9	21.9	75.7	86.6	81.2	18.3	87.9	53.1
584	7.4	6.8	7.1	7.7	7.5	7.6	82.8	52.3	67.6	6.2	93.9	50.1
585	7.4	......	......	7.7	......	......	87.0	......	......	.9	......	......
587	8.6	......	......	13.6	......	......	82.6	......	......	1.1	......	......
588	7.3	......	......	6.9	......	......	89.6	......	......	.5	......	......
589	7.0	......	......	4.7	......	......	91.1	......	......	.5	......	......
591	7.3	6.7	7.0	13.5	4.9	9.2	83.3	84.2	83.8	5.7	82.2	44.0
592	7.2	......	......	9.4	......	......	72.1	......	......	.6	......	......
593	7.6	7.0	7.3	3.7	5.4	4.6	84.3	87.0	85.7	7.1	77.8	42.5
594	7.5	7.3	7.4	4.9	3.1	4.0	79.3	90.5	84.9	7.3	82.1	44.7
600	7.0	......	......	5.0	......	......	78.5	......	......	3.2	......	......
602	7.6	7.4	7.5	4.6	8.5	6.6	89.0	88.4	88.7	4.6	84.0	44.3
604	7.4	7.0	7.2	9.3	15.1	12.2	79.1	64.9	72.0	8.0	92.4	50.2
607	7.4	......	......	7.4	......	......	79.1	......	......	1.6	......	......
Dwarf:												
243	7.6	7.8	7.7	17.1	18.8	18.0	95.6	85.2	90.4	25.4	87.7	56.6
442	8.0	7.9	8.0	29.8	15.9	22.9	92.5	87.8	90.2	16.8	80.4	48.6
535	7.0	7.4	7.2	10.0	18.9	14.5	94.0	78.4	86.2	19.9	80.7	50.3
557	6.3	6.6	6.5	3.1	6.3	4.7	95.3	89.3	92.3	11.8	92.5	52.2
558	7.3	14.5	10.4	4.0	12.1	8.1	93.3	56.4	74.9	7.5	40.0	23.8
559	6.9	6.5	6.7	3.0	......	1.5	90.3	65.6	78.0	2.8	81.9	42.4
564	8.0	7.0	7.5	15.3	4.6	10.0	95.7	89.0	92.4	15.5	77.2	46.4
595	6.8	7.0	6.9	46.3	30.1	38.2	87.1	76.4	81.8	16.9	96.7	56.8
596	6.6	7.7	7.2	5.2	14.9	10.1	95.2	81.4	88.3	24.1	89.8	56.9
597	7.0	7.3	7.2	11.1	9.2	10.2	97.2	88.9	93.1	18.3	86.8	52.6
598	7.0	7.2	7.1	8.5	13.8	11.2	94.3	81.9	88.1	6.8	93.2	50.0
599	6.6	7.2	6.9	5.5	12.4	9.0	92.8	74.5	83.7	12.7	93.0	52.9
605	6.6	14.3	10.5	2.0	24.5	13.3	93.0	74.8	83.9	4.8	68.1	36.5
606	6.4	......	......	5.0	......	......	90.8	......	......	3.3	......	......

[1] Good heads as considered in the nursery work were heads whose conformation was near enough perfect to be used as seed for propagation or for the improvement of the strain.

Dwarf broom corn had a much higher average percentage of stalks headed and a somewhat higher average of good brush in 1917 than the Standard. In 1918 Dwarf broom corn led the Standard in both the average percentage of stalks headed and of good brush, but with a smaller margin than in 1917. This experiment has not been carried far enough to draw final conclusions, but it is very evident that progress is being made in the development of strains of broom corn which produce a uniform brush.

CONCLUSIONS.

The conclusions drawn from the data presented in this bulletin are as follows:

(1) All varieties of broom corn produce high yields in seasons which are favorable, but only adapted varieties yield well in the less favorable seasons.

(2) Dwarf broom corn outyields the Standard variety under such conditions as obtain at Woodward, Okla.

(3) Dwarf broom corn evidently requires less water than the Standard variety and therefore is better adapted to the conditions which prevail in the district described in this bulletin.

(4) The commercial names applied to broom corn have little significance, as they do not represent distinct varieties.

(5) The tendency to sucker is present in both the Standard and the Dwarf varieties of broom corn, but to a greater degree in the Dwarf. Suckering is influenced largely by environing conditions.

(6) Environing conditions also influence the length and quality of the brush. Thick stands tend to produce short brush and thin stands long, coarse brush.

(7) The best time to sow the crop appears to be either from about May 1 to 15 or from June 15 to 30. When sown at these times the crop comes into head either before or not until after the middle of August, which is usually dry and hot.

(8) No single rate of seeding will give the best results in all years. A stand of one plant to 6 or 8 inches of row space, with rows 3.5 feet apart, appears to be the most profitable rate for a series of years.

(9) There is nothing gained by the method of spacing the rows 7 feet apart with the plants twice as thick in the row as when the rows are spaced half that distance apart.

(10) When harvesting is delayed until the seeds have reached the dough stage a higher yield of brush will be obtained than if harvested earlier.

(11) The indications are that better service will be obtained from brooms made from brush harvested when the seeds are in the dough stage than if harvested at any other time.

(12) The nursery work shows that much of the seed from commercial sources is of poor quality. Progress is being made in developing strains which produce a uniform quality of brush.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 837

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. June 3, 1920

CONTROL OF THE GRAPE-BERRY MOTH IN NORTHERN OHIO.

By H. G. INGERSON, *Scientific Assistant*, and G. A. RUNNER, *Entomological Assistant, Deciduous Fruit Insect Investigations.*[1]

CONTENTS.

INTRODUCTION.

The grape-berry moth (*Polychrosis viteana* Clem.) has been the most destructive insect pest with which the grape growers of northern Ohio have ever had to contend. In an effort to improve the methods of control for this insect, extensive experiments in cooperation with the Ohio Agricultural Experiment Station were conducted during the seasons of 1916, 1917, and 1918 in northern Ohio. The results of these experiments and the recommendations based thereon are contained in this paper, together with observations made during the investigation. Only such life-history data are presented as are necessary for the understanding of the control experiments. The complete life-history data will be presented in a later paper.

[1] This investigation was conducted under the direction of Dr. A. L. Quaintance, Entomologist in Charge of Deciduous Fruit Insect Investigations of the Bureau of Entomology. The senior author, assisted by E. R. Selkregg, then field assistant in the Bureau of Entomology, conducted the work during the season of 1916. Much credit is due Dwight Isely of the Bureau of Entomology for his suggestions on grape-insect control, based on similar investigations in the Chautauqua-Erie grape belt of Pennsylvania. The results of Mr. Isely's investigations are published in United States Department of Agriculture Bulletin No. 550. The authors wish to express their appreciation to Prof. H. A. Gossard, entomologist of the Ohio Agricultural Experiment Station, for his help in many ways. To the many grape growers who have cooperated most willingly the authors express their thanks.

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HISTORY IN OHIO.

The grape-berry moth was destructive in Ohio as early as 1869, according to Goodwin.[1] This was shortly after grape production became an extensive industry in the State. In 1881 the insect is recorded as having been especially destructive on the islands in Lake Erie.[1] Injury in Ohio was extensive again in 1905 and 1906, but later decreased and in 1909 and 1910 the berry moth caused comparatively little damage [1, 2]. The infestation became severe again in 1913 and 1914 and reached its height in 1915, when in some local sections as much as two-thirds of the entire crop was ruined. The infestation continued high in 1916, the first season of the investigations here reported, and was but slightly less in 1917. Due to a cold autumn, however, the commercial damage was much less in 1917 than in any one of the four years preceding. In 1918, the last year of these investigations, the infestation about Cleveland was of no commercial importance, but in the section about Sandusky the loss was heavy in many unsprayed Catawba vineyards.

NORTHERN OHIO CONDITIONS AFFECTING INFESTATION.

The grape-berry moth has been a more general pest in the northern Ohio section than in the commercial grape sections of New York, Pennsylvania, or Michigan. This statement is based on published reports [3, 4] and on observations made by the senior author during the seasons of 1914–1918 inclusive.

Four principal factors have brought about this condition: The varieties grown, the cultural practices, the method of harvest, and the training system.

VARIETIES GROWN.

The Catawba variety predominates in the grape section about Sandusky and on the neighboring Lake Erie islands. Due to its late harvest this variety offers ideal conditions for the second-brood larvæ to mature and to reach winter quarters. In all the experimental work conducted the Catawba variety has been uniformly infested more heavily than the Concord, which is the predominating variety in the Chautauqua-Erie belt of Pennsylvania and New York and in Michigan sections.

CULTURAL PRACTICES.

Late in the fall, after grape harvest, a majority of the vineyards are "plowed on." This operation consists in beginning next to the

[1] Goodwin, W. H. The grape-berry worm (*Polychrosis viteana* Clemens). Ohio Agr. Exp. Sta. Bul. 293, p. 259–307 (20 pl. on p. 288–307). 1916.

[2] Gossard, H. A., and Houser, J. S. The grape-berry worm. Ohio Agr. Exp. Sta. Circ. 63. 16 p., fig. 1906.

[3] Johnson, Fred, and Hammar, A. G. The grape-berry moth. U. S. Dept. Agr. Bur. Ent. Bul. 116, Pt. II, p. 15–71, fig. 4–22, pl. 4–8. 1912.

[4] Isely, Dwight. Control of the grape-berry moth in the Erie-Chautauqua grape belt. U. S. Dept. Agr. Bul. 550. 44 p., 9 fig., 6 pl. 1917.

vines and plowing three successive furrows of soil toward the vines. Thus all leaves and trash in the vineyard are covered with from 3 to 5 inches of soil and ideal winter protection is afforded the hibernating pupæ which are in cocoons in the old grape leaves (Pl. II, fig. 2). In the spring before time for moth emergence this soil is worked away from the vines. In the Sandusky region it is plowed away and in grape sections near Cleveland it is removed with a disk or worked away with a shovel cultivator. This cultivation breaks the crust formed in the winter and in many cases turns to the surface the pupæ (Pl. I, fig. 3) that were plowed under the previous fall. This practice of covering the pupæ for the winter and then uncovering them early in the spring protects them from the extreme winter and allows the moths to emerge in the spring.

Pupæ of the berry moth, kept in the insectary yard at Sandusky under conditions similar to those described for the vineyards, lived through the winters of 1916–17 and 1917–18. In the spring of 1917 the emergence was 20 per cent and in 1918, after an unusually severe winter, it was 26 per cent. Comparative data are not at hand for the same winters with pupæ exposed as they would be in a vineyard plowed before grape harvest and then left until spring. In experimental work reported by Isely,[1] however, it was found that subsequent emergence from cocoons left through the winter of 1915–16 under exposed conditions in the vineyard was but 5 per cent as compared with 30 per cent emergence where the cocoons were covered by 2 inches of earth and then uncovered before time for emergence in the spring.

Since late plowing away in the spring is objectionable in northern Ohio from a horticultural standpoint, the writers recommend that when cultivation is completed in July the vineyards, whenever possible, be placed in final cultural condition for the winter and then that they be left in that condition until the next spring. The only objection to this practice is the excessive growth of weeds, which interferes with harvesting. This can be overcome by seeding a cover crop at the completion of cultivation.

METHOD OF HARVEST.

A large part of all the grapes in these sections and practically all of the Catawba variety were formerly sold for wine making. Since no particular packing is required for this market, all sorting is done in the vineyards by the pickers. Wormy berries are cut or shaken out of the clusters and allowed to fall to the ground and to remain in the vineyard. It appears that any other method of disposing of the infested grapes would be more costly in labor than would be warranted now that satisfactory control may be secured by spraying.

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[1] Isely, Dwight, op. cit.

TRAINING SYSTEM.

The "fan" system of grape training (Pl. III, fig. 1) which is used consistently in northern Ohio with the Catawba variety and a modification of which is used with Concords, is not generally practiced in any of the other commercial grape sections of the country.

This "fan" system consists in securing the bearing canes from the old vine head between the ground and the first wire and tying them up obliquely to the first and second wires, forming a V open at the top. Although two canes are the rule with the Catawba variety, when the thrift of the vine allows of more than two the additional canes are also carried up obliquely, completing the fan from which the system takes its name. As the young shoots bearing the clusters grow to a sufficient length they are tied up vertically to the middle and top wires. An effort is made to have these shoots spread, but to economize labor in tying they are often bunched 2 to 4 in a place. This system of training spreads the grape clusters all through the vine from the ground to the top wire and covers them almost completely with foliage and shoots (Pl. III, fig. 2). These conditions explain in part the failure to cover the grape clusters when any set-nozzle method of spraying is used, particularly when the spraying is done late in the season and considerable vine growth has been attained.

VARIETAL INFESTATION.

Several commercial varieties of grapes are present in northern Ohio, affording opportunity for observation on the relative infestation of the different varieties by the grape-berry moth. A list of varieties observed, beginning with the most heavily infested and ending with the least, is as follows: Shride, Elvira, Clinton, Reisling, Catawba, Norton, Niagara, Delaware, Agawam, Ives, Concord, Worden, and Moores Early.

In general it seems that the early-blooming varieties like the Shride and Clinton become heavily infested with the first-brood larvæ, and late-harvested varieties like Catawbas and Nortons become heavily infested with second-brood larvæ.

SEASONAL HISTORY.

The grape-berry moth completes one life cycle and a part of another each season. This insect is injurious only in the larval stage. There are two broods of worms or larvæ every season (Pl. I, fig. 1), the second much more numerous and destructive than the first (Pl. II, fig. 1). Since an understanding of the main points in the life history of the insect is necessary for the best application of control methods, a brief summary will be given.

The winter is spent in the pupal stage in cocoons (Pl. I, fig. 2) which the larvæ spin in grape leaves the previous fall. These leaves are the ones that fall early and become soft and sodden on the ground (Pl. II, fig. 2) and remain under the trellis during the winter. In the spring, previous to and during grape bloom, moths (Pl. I, figs. 4, 5) begin to emerge from the overwintering pupæ. This emergence gradually increases and continues at a high point for about 3 weeks. The moths begin to deposit eggs on the young grapes about 4 days after emergence and the eggs hatch in from 4 to 6 days. This first brood of larvæ or worms usually is not seriously destructive, though first-brood infestation amounting to as much as 30 to 35 per cent has been observed. The average length of the feeding period of this brood of larvæ is 23 days. When mature the larvæ migrate to grape leaves on the vines and spin their cocoons on them. From the cocoons moths emerge in about 13 days and begin laying eggs about 4 days later. The eggs of this second brood are placed on the nearly full-grown grapes and are easily found where the infestation is heavy. Before the eggs hatch they appear as creamy-white raised dots on the green grape berries, but after the larvæ leave the eggs the egg-shells appear as glistening white spots. This brood of eggs hatches in from 4 to 6 days and it is the resultant brood of larvæ that, if allowed to develop, does the greatest damage to the grape crop. (Pl. II, fig. 1.) The larvæ of this brood feed for a long period and usually leave the grapes just before harvest. They spin down to the ground and make their winter cocoons on old decayed grape leaves under the trellis. In the case of a cold fall many larvæ do not leave the grapes but are harvested with the grape crop. This condition prevailed in the fall of 1917 to an unusual degree and the result was a lighter infestation in 1918.

RELATION BETWEEN SEASONAL-HISTORY DATA AND CONTROL MEASURES.

The control experiments recorded in this bulletin are based on extensive field observations and on life-history studies conducted each season. The data shown in diagram form in figure 1 are summarized from the complete seasonal-history data. In determining the hatching periods of the larvæ 4 days are allowed from the emergence of the moths to the deposition of eggs and 6 days for incubation of the eggs. These are average figures from many observations extending over several seasons.

It is seen in figure 1 that in 1916 and 1917 a few larvæ had hatched before Concord grapes began to bloom and in 1918 that the dates of first hatching and beginning of bloom are coincident. In each season the first-brood larvæ were hatching in large numbers for about

3 weeks. It is important to note that the rise in the early part of the hatching is abrupt and the subsidence of hatching more gradual.

It has been the opinion of other writers that the largest part of the second-brood larvæ hatch within a shorter period of time than the first brood. The rearing records here illustrated do not support that belief but show the hatching periods to be of about equal length.

NATURAL CONTROL OF FIRST-BROOD LARVÆ.

It was observed that the grape berries infested by first-brood larvæ dropped readily from the vines when touched. It was thought that if these infested berries dropped in any great numbers at any particular time some cultural method such as covering these berries with soil might aid in the control of the insect. To determine this

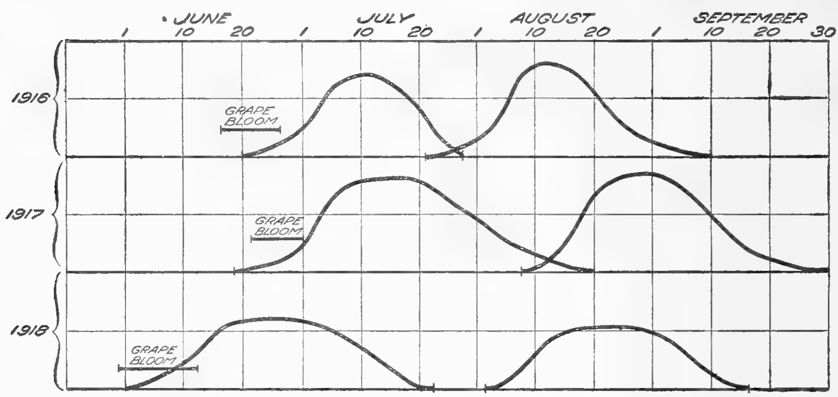

FIG. 1.—Diagram showing relation between dates of spray application and periods during which the grape-berry moth larvæ were hatching for the seasons 1916, 1917, and 1918 at Sandusky, Ohio.

point the following experiment was undertaken in 1916: Wooden frames were made, 6 feet long, 30 inches wide, and 6 inches deep with cheesecloth stretched on the bottoms. These trays fitted between the vines directly under the trellis and were placed in six different locations in the vineyard, under vines heavily infested with first-brood larvæ. Fresh leaves were supplied in the trays for the cocooning of any larvæ that might drop. The trays were put in place July 5 when first-brood infestation was about at its height and were left until August 15, when practically all first-brood larvæ had left the grapes. These trays were examined every three days. Practically no grapes dropped from the vines and not a single larva was taken throughout that period. From these negative results it is concluded that practically no natural control occurs from the dropping of grapes infested by first-brood larvæ.

CONTROL EXPERIMENTS.

STATUS OF SPRAY PRACTICE FOR GRAPE-BERRY MOTH CONTROL.

When these investigations were undertaken the following principal facts were known about spraying for the control of the grape-berry moth: First, satisfactory control had not been effected by the use of any system of set-nozzle spraying, particularly in thrifty vineyards where foliage growth was heavy. Second, satisfactory control had been effected in Ohio[1] by using the trailer method of spraying at the time of the hatchings of second-brood larvæ, usually in early August. This practice, however, left a heavy residue of spray material on the fruit at harvest time, which tended to exclude such fruit from a basket market. Third, two spray applications by the trailer method, the last when the grapes first touched in the clusters, had given satisfactory control on the Concord variety in the Chautauqua-Erie belt in 1915. This practice was to be thoroughly tried in northern Ohio on Concords and Catawbas.

SCOPE OF EXPERIMENTS.

From this summary of the knowledge available it appeared that the investigations should deal with three main points: (1) Time and number of spray applications, (2) chemicals used in spray materials, (3) spray residues left at harvest time.

In studying these factors spraying experiments were conducted by the writers in 6 vineyards in 1916, in 9 in 1917, and in 15 in 1918, a total of 30 vineyards. These vineyards were selected for the opportunity they offered for the advantageous study of any one or more of the important features enumerated above. Since little would be gained by considering each vineyard separately it has seemed desirable to assemble in Tables I, II, and III the data relating to the different vineyards and to bring together in similar form in Table IV the results of the experiments.

TIME OF SPRAY APPLICATIONS.

Former experiments[2] indicated that a spray application directly after grape blooming was important for the control of both grape rootworm beetles and grape-berry moth larvæ. In the Sandusky and island sections of Ohio a spray application following grape bloom is usually made for the control of downy mildew, *Plasmophora viticola*, particularly on Catawba and Delaware varieties. This application directly following grape bloom was considered as the first spray in all of the experiments in which it was included. The second spray

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[1] Goodwin, W. H., op. cit.

[2] Goodwin, W. H., op. cit. Johnson, Fred, and Hammer, A. G., op. cit. Isely, Dwight, op. cit.

was applied when the grapes touched in the clusters, but before the clusters were tight enough to prevent the spray material from being driven between the grapes. This stage of grape growth usually occurs from 3 to 4 weeks after bloom. This second spraying was designed to kill the late hatching first-brood larvæ and to remain on the grapes to be effective when the second-brood larvæ hatched. The third spraying was timed in each case to precede immediately the hatching period of the majority of second-brood larvæ.

METHOD OF APPLICATION.

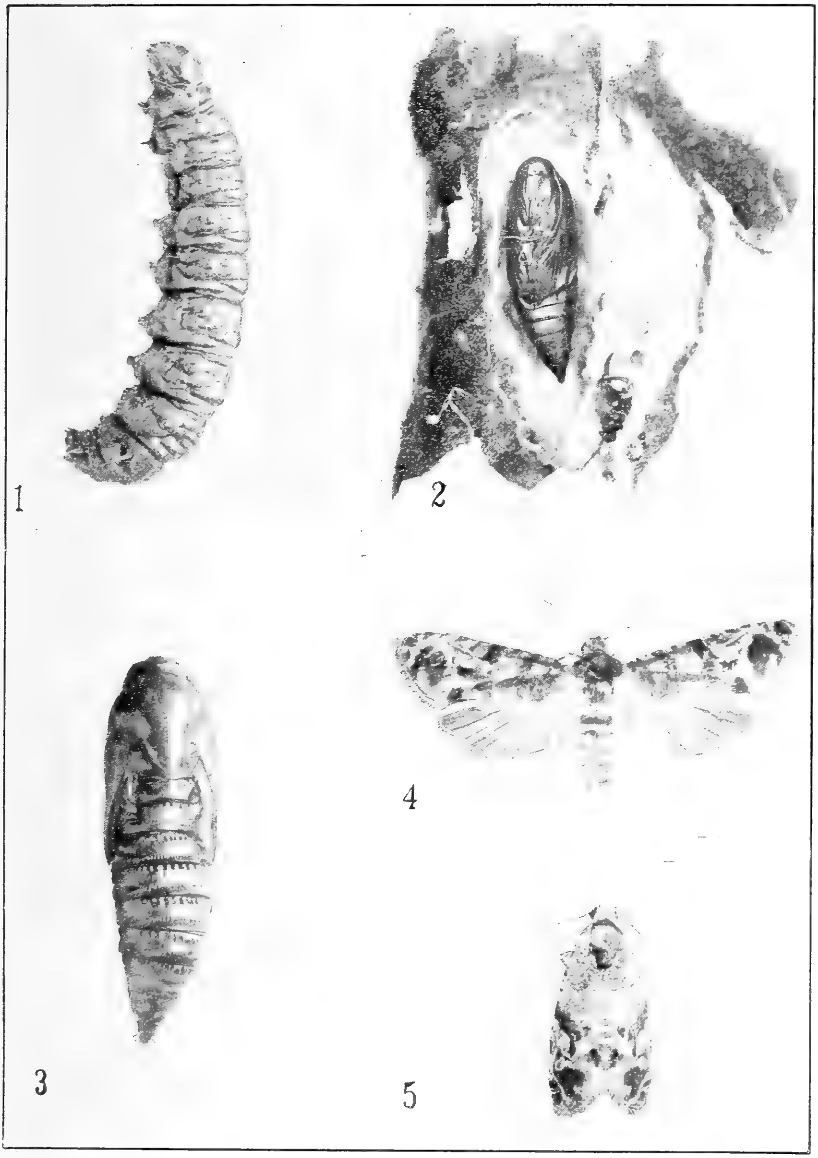
All spraying was done by the hand or trailer method in which 2 hose lines of from 20 to 50 feet trail behind the sprayer, and the spray material is delivered through short spray rods and angle nozzles, directed by hand as in tree spraying. Variations in this method will be discussed later. Sufficient pressure was maintained to drive the spray well into the clusters, but the amount of pressure varied from 125 to 225 pounds in different vineyards. The best pressure to maintain will vary somewhat with the vineyards, but the writers believe that from 175 to 225 pounds usually will be found most efficient. Nozzles set at an angle are absolutely necessary for efficient work, and it was found that nozzles set at angles of 45° allowed more freedom of handling than those set at 90°. A nozzle aperture of $\frac{1}{16}$-inch was most commonly used, but the most efficient size was found to vary with the vineyard and other local conditions.

WEATHER CONDITIONS [1] AFFECTING SPRAY RESULTS.

The season of 1916 was about normal in all respects except for an unusually dry period during July and August which was favorable for spraying and for spray material adhering. These same conditions were likewise favorable for the development of an unusually large second brood of worms. September and October were warm and dry, conditions also favorable to extensive berry moth injury as shown in the uniformly heavy infestation in the checks (Table IV).

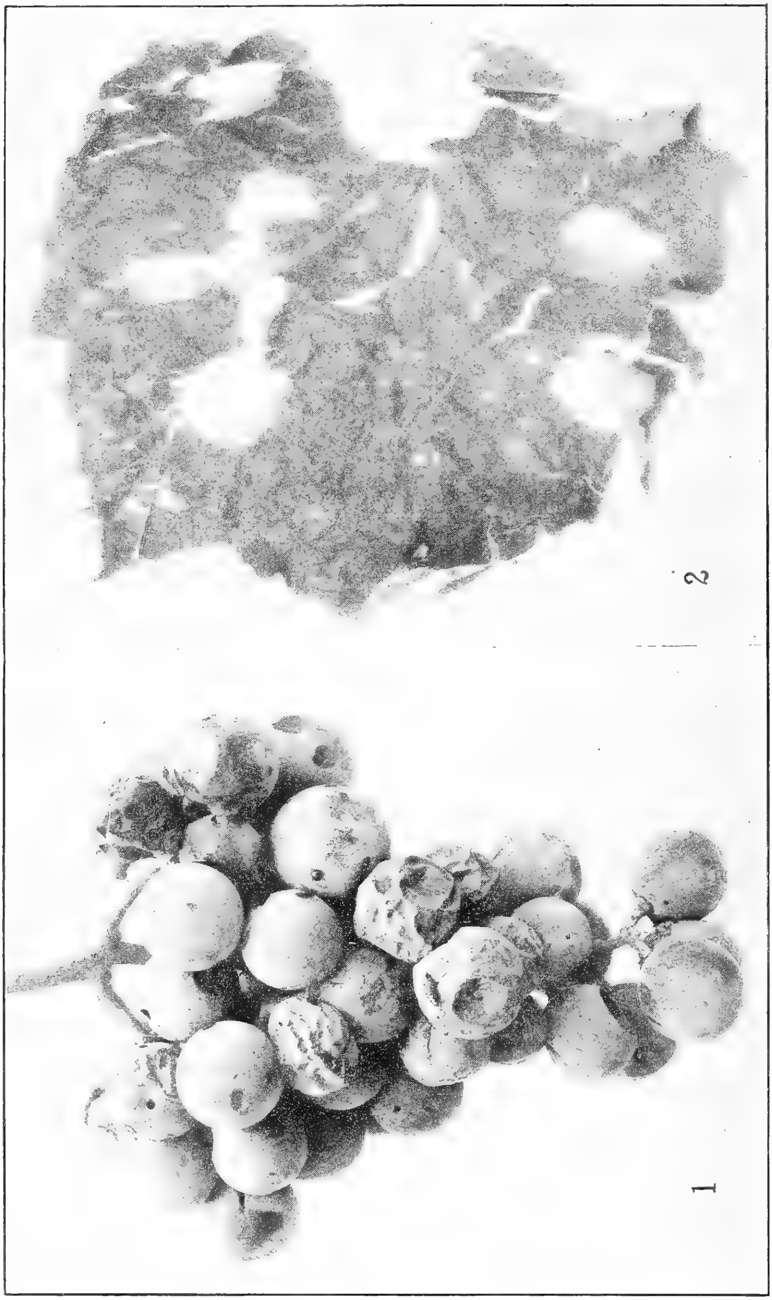
In 1917 conditions were decidedly unfavorable for spraying operations. Both the first and second applications were interfered with by rain and closely followed by showers of varying intensities. In July the total rainfall was but 0.46 inch, but this came between the first and second spray applications. The maturing of first-brood larvæ was favored by an exceedingly hot and dry period from July 28 to August 6 and a subsequent heavy hatching of second-brood larvæ followed. September was 3.3° below normal in temperature and slightly below in precipitation, while October was 8.3° below normal with 3.79 inches of rainfall above normal. These unfavorable

[1] Weather records from the U. S. Weather Bureau Station at Sandusky, Ohio.



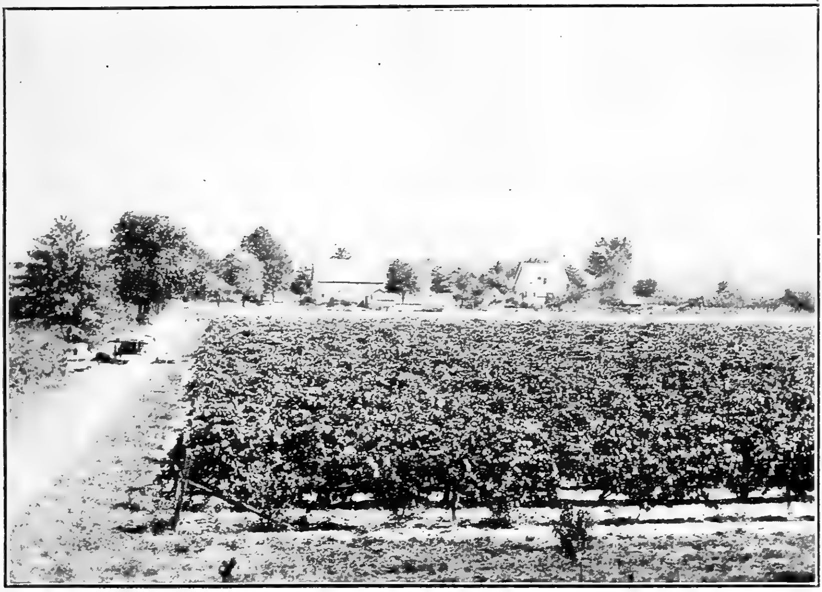
THE GRAPE-BERRY MOTH (POLYCHROSIS VITEANA).

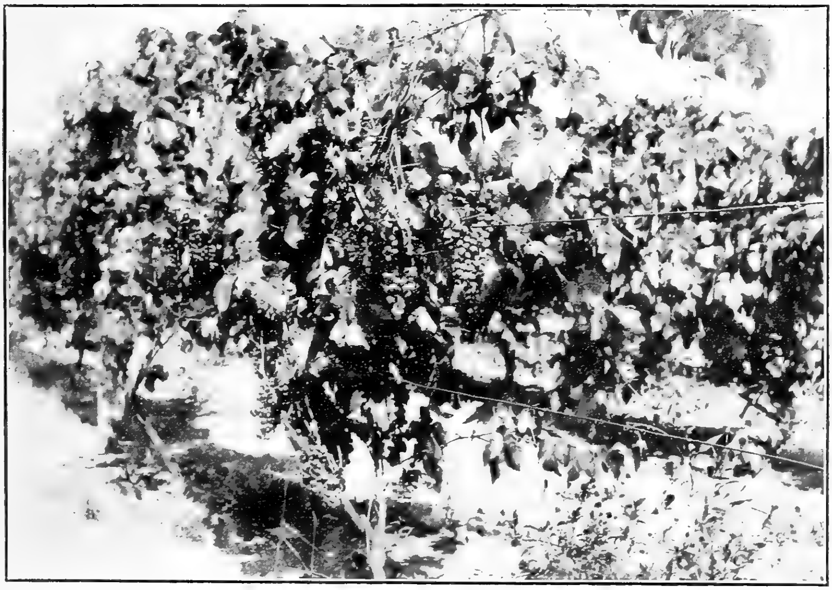
FIG. 1.— Larva. FIG. 2.—Pupa (ventral aspect) in cocoon. FIG. 3.—Pupa (dorsal aspect). FIGS. 4, 5.—Adult. All greatly enlarged.



DAMAGE BY THE GRAPE-BERRY MOTH.

FIG. 1.—Grape cluster at harvest time, heavily infested with second-brood grape-berry moth larvæ. FIG. 2.—Cocoons in sodden grape leaf under trellis.





THE "FAN" SYSTEM OF GRAPE TRAINING.

FIG. 1.—Northern Ohio vineyard trained according to the fan system. FIG. 2.—Grapevine showing fan system of training with grape clusters scattered from near the ground to the top wire.

conditions in September and October retarded the development of second-brood larvæ and counteracted the previous favorable conditions.

The season of 1918 opened unusually early and continued favorable for all growth processes throughout the season. Spraying was but little interfered with and no unusual weather conditions prevailed that affected the spraying results.

SPRAYING EXPERIMENTS IN 1916.

TABLE I.—*Vineyards used for spraying experiments in northern Ohio, 1916.*

Vineyard No.	Vineyard owner and location.	Varieties.	Dates of spray applications.			Estimated infestation 1915.	Gallons of spray material per acre.		
			First.	Second.	Third.		First.	Second.	Third.
						Per ct.			
1	Roland Brown, Kelleys Island.	Catawbas.	July 5	July 21	Aug. 9	70	173	192	192
2	O. W. Brown, Kelleys Island.	....do......	July 3	July 20	....do...	85	120	202	200
3	Charles Duggan, Put-in-Bay.	....do......	June 30	July 17	Aug. 7	75	112	176	112
4	W. R. Huntington, Put-in-Bay.	Catawbas, Concords.	July 1	July 19	Aug. 8	80	105	160	112
5	E. Manty, Venice.......	....do......	June 29	July 12	Aug. 3	90	128	304	150
6	John Schonhart, Venice.	....do......	June 27, 28.	July 11, 12.	Aug. 2	70	90	236	230

Experiments were conducted in six vineyards in the Sandusky and island sections, as shown in Table I. In all of these experiments the arsenicals were applied in Bordeaux either 3–3–50 or 2–3–50 strength. Laundry soap at the rate of 2 pounds to 50 gallons was used for the first spray application in all of the vineyards and for the second spray in vineyards Nos. 5 and 6. It became apparent during the second spray application that resin fish-oil soap possessed better spreading qualities than laundry soap and so it was used in all the other spray applications at the rate of 1 pound to 50 gallons. Previous to bloom all of the vineyards received an application of Bordeaux alone for the control of downy mildew. The strength of arsenicals in the berry-moth sprays was varied in the different vineyards as shown in Table VI.

SPRAYING EXPERIMENTS IN 1917.

TABLE II.—*Vineyards used for spraying experiments in northern Ohio, 1917.*

Vineyard No.	Vineyard owner and location.	Varieties.	Dates of spray applications. First.	Dates of spray applications. Second.	Dates of spray applications. Third.	Estimated infestation 1916.	Control of grapeberry moth in 1916.	Gallons of spray material per acre. Spray applications. First.	Second.	Third.
						Per ct.				
1	Becker Wine Co., Kellys Island.	Catawbas.	July 14	Aug. 3, 4	....	25	(1)	150	193	......
2	O. W. Brown, Kelleys Island.	....do......	July 12	Aug. 2	....	50	(2)	165	178	......
3	Paul Cooley, Dover Center.	Concords..	July 12, 13.	July 26	Aug. 18	40	(3)	250	300	300
4	Fred Foye, Put-in-Bay.	Catawbas.	July 11, 12.	July 31, Aug. 1.	....	90	(3)	150	233	......
5	George Lewis, Bay Village.	Concords, Ives.	July 5-9	July 23-26.	Aug. 17	40	(3)	200	275	200
6	John Schonhart, Venice.	Catawbas, Concords.	July 3, 4	July 20-25.	Aug. 14	20	(4)	150	312	280
7	T. W. Wearsch, Avon Lake.	Concords, Ives.	July 10	July 27	Aug. 17	90	(3)	120	160	160

[1] One spray with trailers.
[2] Two sprays with trailers but operators riding.
[3] No spray.
[4] Two sprays with trailers.

As seen in Table II the experiments were conducted in seven vineyards, four in the Sandusky and island sections and three in the Dover and Avon sections just west of Cleveland, Ohio. The experiments were so placed as to include local variations in the different grape sections, such as weather, cultural practices, varieties, and markets. All the arsenicals were applied in Bordeaux 2–3–50 with resin fish-oil soap added at the rate of 1 pound to 50 gallons. The following single exception was made: In vineyard No. 5 copper sulphate was omitted from the third spray application and laundry soap, 2 pounds to 50 gallons, was substituted for resin fish-oil soap.

SPRAYING EXPERIMENTS IN 1918.

TABLE III.—*Vineyards used for spraying experiments in Northern Ohio, 1918.*

Vineyard No.	Vineyard owner and location.	Varieties.	Date sof spray applications. First.	Date sof spray applications. Second.	Date sof spray applications. Third.	Estimated infestation 1917.	Control of grapeberry moth in 1917.	Gallons of spray material per acre. Spray applications. First.	Second.	Third.
						Per ct.				
1	C. D. Powell, Vermilion.	Ives.......	June 13, 14.	July 9	Aug. 5	15	(1)	(2)	(2)	(2)
2	O. W. Brown, Kelleys Island.	Catawbas.	June 29	July 18	....	15	(1)	(2)	(2)	(2)
3	T. W. Wearsch, Avon Lake.	Concords, Ives.	June 14, 15.	July 11, 12.	....	2	(1)	100	150	......
4	Ernest Dunning, Avon Lake.	Concords..	June 19	July 16	....	50	(3)	200	342	......
5	V. Doller, Put-in-Bay.	Catawbas.	July 2-3	Omitted.	....	75	(3)	(2)	(2)	......

[1] Two sprays with trailers. [2] No record. [3] No spray.

The experiments were extended in 1918 to include work in 15 vineyards, but as infestation was not sufficiently heavy for satisfactory comparisons in all the vineyards only the 5 showing the heaviest infestations are included in Tables III and IV.

The arsenicals were applied in Bordeaux 2–2–50 in vineyards Nos. 1, 2, and 5. In vineyards Nos. 3 and 4 copper sulphate was omitted at the request of the owners. Stone lime 2 pounds to 50 gallons was retained to care for any free arsenic in the arsenicals. Resin fish-oil soap at the rate of 1 pound to 50 gallons was used uniformly throughout the experiments.

METHOD OF RECORDING RESULTS OF SPRAYING EXPERIMENTS.

It had been learned in earlier work [1] that results based on weights of harvested fruit were misleading, owing to the varying thrift of vineyards, time of harvest, weather conditions affecting the development of worms, etc. The weight method, therefore, was abandoned in favor of the count method. This consists in selecting a representative number of vines in each sprayed plat and in each check, harvesting all the fruit from these vines, counting the clusters, then the clusters containing wormy berries, then removing the wormy grapes and counting them. To ascertain the average number of grapes per cluster, 100 representative clusters were taken in each vineyard and all the grapes counted. The number of clusters in each plat was then multiplied by the average number of grapes per cluster to give the total number of grapes examined in each plat.

In all control work on the grape-berry moth, the unevenness of infestation within a vineyard has made experimental results difficult to interpret. This uneven infestation prevailed throughout these investigations but was cared for whenever possible by placing checks across the control plats and reading the results on the control plat the second post-length away from the checks. While the plan does not entirely overcome the difficulty, the writers feel that the averages from several vineyards closely approximate actual conditions.

In all cases the fruit from at least 10 vines was examined and when possible the examinations included all the fruit from 20 to 25 vines. Exceptions to this occurred only when there were less than 10 vines of a particular variety in a plat. First-brood counts were made in some instances, but since they add little to the final results they are omitted from the tables.

[1] Johnson, Fred, and Hammar, A. G., op. cit.; Isely, Dwight, op. cit.

SUMMARY OF RESULTS BY VINEYARDS, TIME AND NUMBER OF SPRAY APPLICATIONS, 1916, 1917, 1918.

TABLE IV.—*Summary by vineyards of spraying results for control of the grape-berry moth, Sandusky, Ohio, seasons 1916, 1917, 1918.*

[All spray applications made by the hand or trailer method.]

Spray mixture.			Combination of spray applications.			Varieties used.	Vineyard No. 1.		Vineyard No. 2.		Vineyard No. 3.		Vineyard No. 4.		Vineyard No. 5.		Vineyard No. 6.		Vineyard No. 7.		Averages of all vineyards.	
Number of applications.	Arsenate of lead powder.	Material.	First. 3 to 5 days after bloom falls.	Second. When grapes touch in the clusters.	Third. When second-brood larvæ begin to hatch.		Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.
	Lbs.	*Galls.*																				
SEASON 1916.																						
2	2½	50	X	X		Catawbas	31.59	98.26	28.29	63.50	6.28	78.75			22.74	94.99	10.41	64.39			19.86	79.98
						Concords							3.25	64.52	10.20	90.93	3.34	43.32			5.59	66.25
2	2½	50	X		X	Catawbas	33.54	98.26			8.27	78.75					15.17	77.93			18.99	83.98
						Concords											2.31	41.16			2.31	22.67
2	2½	50		X	X	Catawbas					7.67	78.75	1.37	81.12			8.31	77.93			5.78	79.27
						Concords											2.66	22.67			2.66	22.67
2	1½	50	X	X		Catawbas							.93	81.12			11.90	70.26			6.41	75.69
						Concords											5.56	52.83			5.56	52.83
3	2½	50	X	X	X	Catawbas	16.96	98.26	9.06	63.50	3.62	78.75			2.48	94.99	2.18	64.39			6.86	79.98
						Concords							2.26	64.52	1.48	90.93	.21	43.32			1.32	66.26
3	1½ 2½	50 50	X, 1½ lbs.	X, 1½ lbs.	X, 2½ lbs.	Catawbas							.81	81.12							.81	81.12
1	2½	50		X		Catawbas					13.30	78.75	2.37	81.12			22.78	74.24			12.82	78.04
						Concords											11.48	33.68			11.48	33.68
SEASON 1917.																						
2	2½	50	X	X		Catawbas	0.67	64.09	6.47	79.31			7.72	79.63							4.95	74.34
						Concords											0.48	30.14			.48	30.14
						Ives											2.11	39.67			2.11	39.67

						Catawbas	2.03	64.09	8.86	78.17			5.84	63.03			1.48	42.00			4.55	61.82
2	1½	50	X	X		Concords					.47	61.61			.84	32.11	.18	20.60	2.66	88.03	1.04	50.57
						Ives									.43	20.14	2.94	19.59			1.68	19.86
2	1½	50	X		X	Concords					.83	46.52					1.40	24.77			1.11	35.64
						Ives									1.64	20.14	.85	39.67	2.55	88.03	1.68	49.28
						Catawbas											.41	42.00			.41	42.00
3	1½	50	X	X	X	Concords					1.16	61.61			.42	32.11	.60	30.09	2.66	88.03	1.21	52.96
						Ives											1.67	19.59			1.67	19.59
2	1½	50	X, 1½ lbs.	X, 2½ lbs.		Catawbas	.95	64.09	20.11	82.25			4.49	63.03			.54	32.92			6.52	60.57
	2½	50				Concords											.70	32.68			.70	32.68
						Catawabs			28.07	83.36			13.87	79.63							20.97	81.49
1	2½	50		X		Concords											.94	30.14			.94	30.14
						Ives											7.23	39.67			7.23	39.67
1	1½	50	X			Concords					20.64	46.52									20.64	46.52

SEASON 1918.

						Catawbas			4.78	68.02											4.78	68.02
2	1½	50	X	X		Concords					0.41	2.54	1.00	6.28							.71	4.41
						Ives	0.86	7.85													.86	7.85
2	1½	50	X		X	Ives	2.46	11.00													2.46	11.00
3	1½	50	X	X	X	Ives	.95	16.24													.95	16.24
2	1	50	X	X		Catawbas			7.39	62.36											7.39	62.36
						Ives	2.08	6.93													2.08	6.93
1	1½	50		X		Catawbas			25.67	82.82											25.67	82.82
						Ives	4.20	10.04													4.20	10.04
						Catawbas									5.09	17.19					5.09	17.19
1	1½	50	X			Concords							5.95	6.28	6.27	21.37					6.11	13.83
						Ives					8.75	9.89									8.75	9.89

In Table IV are brought together all of the data bearing on the time and number of spray applications, arranged by vineyards and varieties. This table provides for a comparison of the plats within each vineyard by reading from top to bottom, as well as a comparison of the plats receiving similar spray treatment in the different vineyards, by reading across. While the comparison between plats within a vineyard is relatively consistent, considerable variations exist between vineyards. A study of the column of averages shows satisfactory commercial control to have been effected in all plats which received either two or three spray applications with the exceptions of the first two plats. These two plats illustrate the necessity of timeliness of spraying and adhesiveness of spray material, since in 1917 the more timely spray treatment, and the use of resin fish-oil soap throughout, reduced the average infestation from 19 per cent in 1916 to 5 per cent in 1917.

RELATIVE EFFICIENCY OF DIFFERENT TIMES AND NUMBERS OF SPRAY APPLICATIONS.

TABLE V.—*Summarized results from Table IV—relative efficiency of different times and numbers of spray applications, 1916, 1917, and 1918—Arsenicals applied in Bordeaux mixture and soap solution.*

Number of applications.	First, 3 to 5 days after bloom.	Second, when grape berries touch in cluster.	Third, when second-brood larvæ begin to hatch.	Arsenate of lead powder, pounds to 50 gallons material.	Years tried.	Number of vineyards.	Number of plats.	Percentage of grape berries infested, averages of all experiments, 1916, 1917, 1918. Catawbas. Sprayed plat.	Catawbas. Adjacent check.	Concords. Sprayed plat.	Concords. Adjacent check.	Ives. Sprayed plat.	Ives. Adjacent check.
2	X	X	......	2½	1916, 1917	9	11	11.35	79.22	3.04	48.20	2.11	39.67
2	X	......	X	2½	1916	3	4	18.99	83.98	2.31	22.67	......	......
2	X	X	......	1½	1917, 1918	11	14	4.67	64.92	.82	26.00	1.53	16.85
2	X	......	X	1½	1917, 1918	5	6	......	......	1.11	35.64	2.07	30.14
2	......	X	X	2½	1916	3	4	5.78	79.27	2.66	22.67	......	......
3	X	X	X	2½	1916	6	8	6.86	79.98	1.32	66.26	......	......
3	X	X	X	1½	1917, 1918	5	5	.41	42.00	1.21	52.96	1.31	17.92
1	......	X	......	2½	1916, 1917	6	7	16.90	79.77	6.21	31.91	7.23	39.67
1	X	......	......	1½	1917, 1918	4	4	......	......	13.30	26.40	8.75	9.89
2	X	X	......	1	1918	2	2	7.39	62.36	......	......	2.08	6.93
1	......	X	......	1½	1918	2	2	25.67	82.82	......	......	4.20	10.04

A comparison of the combinations of the first and second sprays with first and third sprays shows little choice between them as far as berry-moth control is concerned. Since the combination of the first and second sprays leaves the fruit practically free of all spray residue at harvest time and since the second spray is more easily applied than the third because of lighter grape foliage, this combination of the first and second application is preferred by the writers. It is important to know, however, that if for any reason the second spray can not be made, the third may be applied and will give about equally as good control. When the third application is made the fruit will usually be unfit for basket market because of excessive spray residue.

Where a third application is added to the first and second, control is slightly better, 6.8 per cent infestation as compared with 11.3 per cent in 1916 and 0.4 per cent as compared with 4.6 per cent, an average for 1917 and 1918. These differences, however, were not sufficient to justify the expense of the third application.

ONE-SPRAY METHOD.

One spray application by the trailer method at the time the grapes first touched in the clusters gave an average control of 83 per cent on Catawbas and 94 per cent on Concords as compared with 89 per cent control on Catawbas and 97 per cent on Concords when both the first and second sprays were given. This is a good showing for a "one-spray" schedule and this treatment might be the most efficient under some conditions. All results indicate that this one spray may be depended upon to save the crop from ruin by the berry moth.

In an effort to eliminate entirely the factor of spray residue on fruit for the basket market the spray application directly after grape bloom was tried alone. Data are insufficient on this treatment but indicate a marked effect on the final infestation. This treatment has the advantages of being the most important one for rootworm beetle control and of being timely to prevent black-rot infection of the young grapes. It may develop that this method will be practical after the infestation of the moth has been reduced by the use of the two-spray schedule for one or more years. Experiments on this point were conducted in several vineyards in 1918 but adjacent checks failed to show sufficient infestation to make results conclusive.

CONCLUSIONS FROM EXPERIMENTS.

The combinations of the first spray treatment with the second and of the first with the third gave satisfactory control. The third spray added to the first and second increased the effectiveness, but not enough to justify the expense of making the application. The second application alone averaged 83 per cent control and in all cases saved the commercial crop. The first application alone reduced the final infestation appreciably but needs further testing.

MATERIALS USED IN SPRAYS.

ARSENICALS.

ARSENATE OF LEAD, COMMERCIAL POWDER.

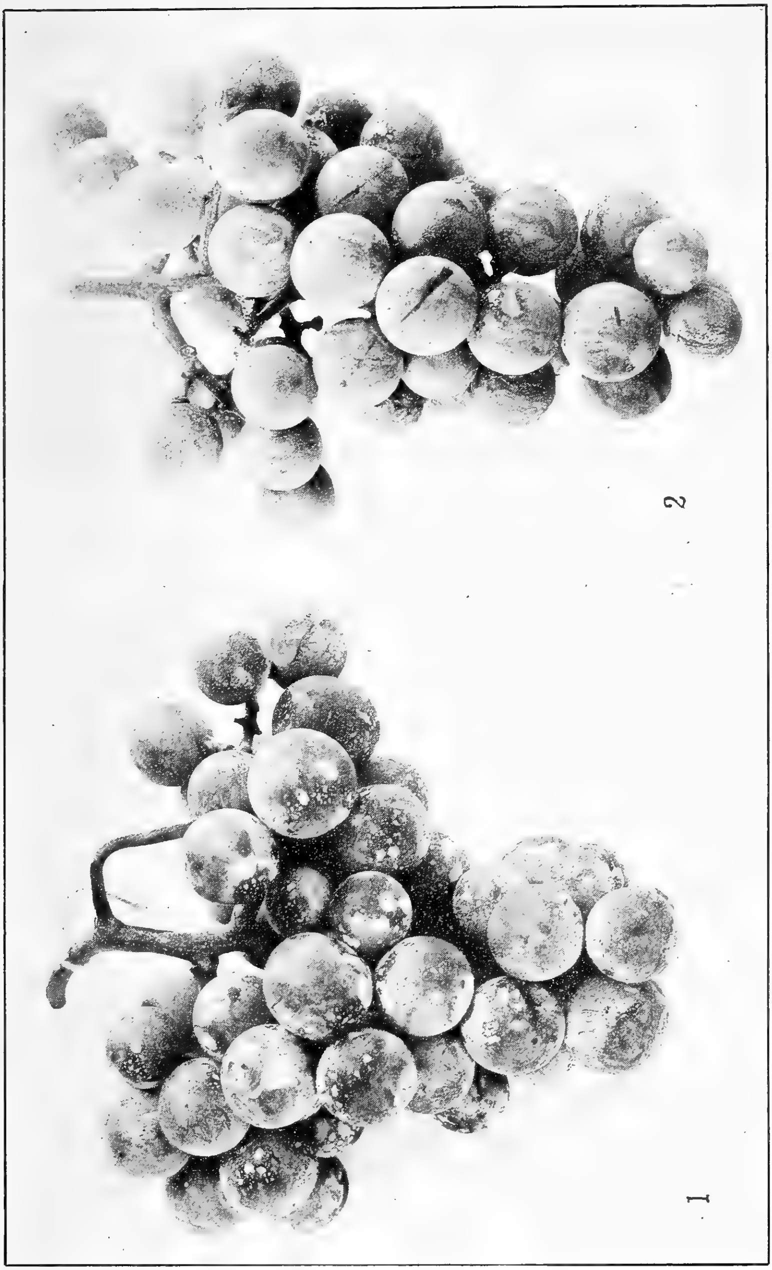
Arsenate of lead in powder form was used throughout this work. Since previous infestation had been extremely heavy in the experimental vineyards, the powder was used in 1916 at the rate of $2\frac{1}{2}$

pounds to 50 gallons, equivalent to 5 pounds of paste to 50 gallons, as a basis for comparison that year. The 1½-pound rate was used in but two vineyards in 1916. In 1917 the 2½-pound rate was retained in four vineyards and the 1½-pound used in seven. In 1918 comparison was made between 1 pound and 1½ pounds of arsenate of lead powder.

TABLE VI.—*Relative efficiency of arsenate of lead at the rate of 1, 1½, and 2½ pounds (powder) to 50 gallons liquid.*[1]

Pounds of arsenate lead powder to 50 gallons liquid	Spray applications.		Number of vineyards.	Number of plats.	Vineyard No.	Percentage of infested grape berries.					
						Catawba variety.		Concord variety.		Ives variety.	
	3 to 5 days after grape bloom.	When grapes touch in clusters.				Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.
SEASON 1916.											
1½	X	X	2	3	4	0.93	81.12				
	X	X			6	11.90	70.26	5.56	52.83		
Averages			2	3		6.42	75.69	5.56	52.83		
2½	X	X	2	3	4			3.25	64.52		
	X	X			6	10.41	64.39	3.34	43.32		
Averages			2	3		10.41	64.39	3.30	53.92		
SEASON 1917.											
1½	X	X			1	2.03	64.09				
	X	X			2	8.86	78.17				
	X	X			3			0.47	61.61		
	X	X			4	5.84	63.03				
	X	X			5			.84	32.11	0.43	20.14
	X	X			6	1.48	42.00	.18	20.60	2.94	19.59
	X	X			7			2.66	88.03		
Averages			7	10		4.55	61.82	1.04	50.59	1.68	19.86
2½	X	X			1	.67	64.09				
	X	X			2	6.47	79.31				
	X	X			4	7.72	79.63				
	X	X			6			.48	30.14	2.11	39.67
Averages			4	5		4.95	74.34	.48	30.14	2.11	39.67
SEASON 1918.											
1½	X	X			1					0.86	7.85
	X	X			2	4.78	68.02				
	X	X			3			0.41	2.54		
	X	X			4			1.00	6.28		
Averages			4	4		4.78	68.02	.71	4.41	.86	7.85
1	X	X			1					2.08	6.93
	X	X			2	7.39	62.36				
Averages			2	2		7.39	62.36			2.08	6.93

[1] All plats received Bordeaux 2-3-50 and resin soap 1 pound to 50 gallons in 1917 and 1918. Same in 1916, except laundry soap 2 pounds to 50 gallons, first application; and second application vineyards Nos. 5 and 6.



SPRAYING AGAINST THE GRAPE-BERRY MOTH.

Comparative spreading qualities in spray mixture of a laundry soap (fig. 1) and a resin fish-oil soap (fig. 2).

The differences in the control effected by the various strengths of arsenate of lead were slight, as shown in Table VI. When comparing the averages the differences in the infestation of the adjoining checks should be kept in mind. The tests of 1 pound to 50 gallons have not been sufficient to justify one in drawing conclusions, but $1\frac{1}{2}$ pounds to 50 gallons has proved adequate for control.

ARSENATE OF CALCIUM, COMMERCIAL POWDER.

Much interest has centered in the comparative merits of arsenate of calcium and arsenate of lead as insecticides. Arsenate of calcium has the advantage of being much cheaper than arsenate of lead, but doubt has prevailed as to its adhesive qualities and its effect on foliage. Since an extra spreader and adhesive in the form of resin soap is necessary even with arsenate of lead for spraying grape clusters, and since grape foliage is comparatively hardy to arsenicals, it was thought that arsenate of calcium should have a wide use in grape spraying.

TABLE VII.—*Relative efficiency of commercial arsenate of calcium and arsenate of lead for control of the grape-berry moth, Sandusky, Ohio, 1917, 1918. Both arsenicals applied in Bordeaux 2–3–50 with 1 pound of resin soap to each 50 gallons.*

Arsenical, pounds to 50 gallons.	Spray applications.		Number of vineyards.	Number of plats.	Vineyard No.	Percentage of infested grape berries.					
	3 to 5 days after grape bloom.	When grapes touch in clusters.				Catawba variety.		Concord variety.		Ives variety.	
						Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.	Sprayed plat.	Adjacent check.
Arsenate of calcium commercial powder, 42 per cent As_2O_5, 1 pound to 50 gallons	X	X	......	......	1917.						
					1	9.46	64.09	......	......	......	......
					4	13.78	79.63	......	......	......	......
					5	......	......	0.58	32.11	......	......
					6	......	......	.66	40.60	1.28	39.67
					1918.						
					1	......	......	......	......	1.04	6.23
					2	7.22	87.06	......	......	......	......
Averages	......	......	6	7	......	10.15	76.93	.62	36.35	1.16	22.95
Arsenate of lead commercial powder, 30 per per cent As_2O_5	X	X	......	......	1917.						
					1	2.03	64.09	......	......	......	......
					4	5.84	63.03	......	......	......	......
					5	......	......	.84	32.11	......	......
					6	......	......	.18	20.60	2.94	19.59
					1918.						
					1	......	......	......	......	.86	7.85
					2	4.78	68.02	......	......	......	......
Averages	......	......	6	7	......	4.22	65.05	.51	26.35	1.90	13.72

Table VII shows the comparison of arsenate of calcium with arsenate of lead in six vineyards and seven plats. Control was almost complete for both materials on the Ives and Concord varieties. On the Catawbas the arsenate of calcium averaged 90 per cent control and the arsenate of lead 96 per cent, but the checks adjacent to the arsenate of calcium plats were 12 per cent more heavily infested than those adjacent to the arsenate of lead plats so the comparisons are very close. These results may indicate that the arsenate of lead adhered slightly longer in the season than the arsenate of calcium. In recording the spray residue on the fruit at harvest time, slightly less was found on the arsenate of calcium plats than on corresponding arsenate of lead plats. This feature is an advantage in grape-berry moth spraying and is discussed later. No foliage injury that could be attributed to the arsenical occurred on any of the arsenate of calcium plats.

Grape spraying experiments were continued in 1919 and foliage injury occurred on all plats of the Ives variety where commercial arsenate of calcium was used at the rate of $1\frac{1}{5}$ pounds to 50 gallons of water with 3 pounds of freshly burned stone lime slaked and added to each 50 gallons of spray solution. This experience indicates that the use of arsenate of calcium on the Ives variety is unsafe.

ARSENATE OF CALCIUM, HOME-MADE PASTE.

Varied success had been reported from the use of home-made arsenate of calcium pastes as sprays for fruit trees. To determine the efficiency of these home-made materials for use in sprays on grapes the following experiments were conducted. Pastes were made according to the following formulas and methods and applied in spray solutions to grapes:

(1) Arsenate of soda + stone lime.

Sodium arsenate, fused (dry powdered) 60 per cent As_2O_5 ounces	30
Stone lime do	18
Water do	48
Total do	96

The sodium arsenate was dissolved in the water and the resultant solution used to slake the lime. A smooth paste arsenate of calcium of about 18 per cent As_2O_5 content resulted. This was decanted 5 times to remove the sodium hydroxid. The resultant paste was used at the rate of $2\frac{1}{2}$ pounds to 50 gallons to be comparable with arsenate of lead (commercial powder 30 per cent As_2O_5), $1\frac{1}{2}$ pounds to 50 gallons.

(2) Arsenic acid + stone lime.

Arsenic acid (liquid) 78 per cent As_2O_5 ounces	10
Stone lime do	8
Water do	34
Total do	52

The lime was slaked to a smooth paste with 18 ounces of water. The arsenic acid was diluted with the remaining 16 ounces of water and the diluted acid added to the lime paste a little at a time. The paste was stirred vigorously during the mixing. With each addition of acid the lime had a tendency to granulate, but continued stirring restored the smooth pasty condition. A sample of the final paste was analyzed by the United States Bureau of Chemistry under miscellaneous laboratory No. 24714 as follows:

Moisture	69.7
Total CaO (as received)	15.08
Total As_2O_5 (as received)	12.04
Water soluble As_2O_5	.02

5 grams samples in 1,000 c. c. CO_2 free water; equivalent to 2 pounds to 50 gallons. Free lime calculated as calcium hydroxid $Ca(OH)_2$ 4.4 per cent.

Paste made according to this formula was used on grapes in 1918 at the rate of 4 pounds to 50 gallons of water. Grape-berry moth infestation failed to develop in numbers sufficient for the desired comparisons in any one of the four vineyards in which these materials were used. The spreading qualities and effects on grape foliage, however, are important. The arsenicals were applied either in Bordeaux 2–2–50 or with stone lime 2 pounds to 50 gallons added to the mixture. In all cases resin fish-oil soap at the rate of 1 pound to 50 gallons was also added. The paste made from sodium arsenate spread equally as well as the commercial arsenate of calcium powder or arsenate of lead powder. The paste made from arsenic acid failed to spread as well and when dry it was not a smooth, even coating such as is desired. In no case could foliage injury be attributed directly to the use of either of the home-made arsenate of calcium pastes.

Spreaders and Adhesives.

Because of the partial failure of arsenate of lead and Bordeaux to spread over or " wet " the individual grapes in the grape clusters, various materials have been added to these to facilitate the spreading process.

The qualities desired in such a spreader are (1) quick-wetting power, (2) adhesive power when dry, and (3) that it be easily prepared for use. In addition, a material to be suitable must be compatible with Bordeaux mixture and arsenicals and also be comparatively cheap.

Former investigations[1] had shown that some form of soap was the most practical material for the purpose. When these investigations were undertaken various soaps were recommended by differ-

[1] Isely, Dwight, op. cit.

ent authorities. To determine the most efficient of these, experiments as shown in Table VIII were conducted in 1916.

TABLE VIII.—*Relative efficiency of different soaps as spreaders and adhesives, Schonhardt vineyard, Venice, Ohio, 1916.*

Kind of soap used.	Pounds in 50 gallons.	Spray materials combined with soaps.	Gallons spray material per plat second application.	Increase over resin soap.	Results in grape-berry moth control.				
					Number vines examined.	Number clusters examined.	Number grapes examined.	Infested grapes.	Variety.
				Per ct.				*Per ct.*	
Soft	2	(1)	140	86	14	790	18,960	17.04	Concords.
					10	342	12,996	24.83	Catawbas.
Laundry	2	(1)	100	33	11	608	14,592	6.78	Concords.
					10	198	7,524	6.11	Catawbas.
Resin fish-oil	1	(1)	75	0	12	735	17,640	8.50	Concords.
					10	311	11,918	8.37	Catawbas.
Checks					22	1,050	25,200	41.16	Concords.
					34	1,019	30,570	73.12	Catawbas.

[1] Bordeaux 3-3-50, arsenate of lead commercial powder 2½ pounds to 50 gallons.

Adjoining grape rows, each row including Concord and Catawba varieties, were sprayed three times during the season, the first application three to five days after grape bloom, June 27, the second when the grapes touched in the clusters, July 13, and the third at the beginning of the hatching period of second-brood larvæ, August 3. All spraying was done by the trailer method with medium disk angle nozzles and at a pressure of 150 pounds. The soaps were used as spreaders in mixtures of Bordeaux 3-3-50 and arsenate of lead powder 2½ pounds to 50 gallons. The season was unusually dry during July and August, favoring both adherence of spray materials and the development of the grape-berry moth. The Concords were harvested September 29 and the Catawbas October 10.

The soft soap used was a bulk product made especially for use in commercial laundries. This soap dissolved readily in hot water, but when applied to grapes formed in globules on the leaves and grape berries and dried in large drops. This condition was reflected in the percentages of infested grapes at harvest time, 17 per cent on Concords and 25 per cent on Catawbas. This increase in infestation on the Catawba variety did not occur with the laundry or resin soap, and so seems to indicate less adhesive power late in the season in the soft soap, since the Catawbas were harvested 12 days later than the Concords. The laundry soap used (Pl. IV, fig. 1) was the common yellow-bar soap, chipped and dissolved in hot water. This spread smoothly over the grape foliage and berries and gave a satisfactory covering when the spray was directed on the clusters for a sufficiently long time, but the amount required to "wet" them was 33 per cent greater than when the resin soap was used. When the third-spray application is used, as in this experiment, the adhesive quality of the laundry soap appears equally as great as that of the resin. However, when the first and second sprays are applied and the third omitted, leaving a longer period between the last spray application and harvest time, it appears from field observations that the resin soap adheres longer than the laundry soap.

The resin fish-oil soap used was the commercial product obtained in bulk and of the consistency of thick molasses. This soap is readily dissolved in hot water and wets the clusters (Pl. IV, fig. 2) easily, as is indicated by the use of but 75 gallons as compared with 100 gallons of laundry soap solution and 140 of soft soap solution. The resin soap adhered the longest of any material tried. It was found that 1 pound of this soap to 50 gallons was about as efficient as 2 pounds of the other soaps and at the rate of 1 pound to 50 gallons is as cheap. No difference in compatibility with Bordeaux and arsenate of lead could be noted among the different soaps.

In conclusion it can be said that the resin fish-oil soap proved to have all the desired qualities of a spreader and adhesive and in the present state of knowledge appears the best spreader to use in grape spraying.[1]

Combination Sprays.

In the Sandusky and Lake Erie island sections where the Catawba variety predominates it is desirable to combine a fungicide for control of downy mildew, *Plasmophora viticola*, with the arsenical and soap for rootworm beetle and grape-berry moth control. In the other sections it is sometimes desirable to use the same combination for blackrot and insect control.

Bordeaux, either 2–2–50, 2–3–50, or 3–3–50, was used in combination with arsenate of lead powder $1\frac{1}{2}$ and $2\frac{1}{2}$ pounds to 50 with soaps at the rate of 1 and 2 pounds to 50. In some of the experiments the copper sulphate was omitted and stone lime, 2 pounds to 50 gallons, was used. The combining of the insecticide with the fungicide appeared to make no difference in insect control.

In some cases slight burning of Concord and Catawba foliage and serious burning of Ives foliage resulted from application of the Bordeaux-arsenate of lead-soap combination. The burning was most noticeable during the abnormally wet season of 1917. Experiments were conducted in 1918 to determine the material or combination causing the burning. The combinations of arsenate of lead and soap with Bordeaux proved responsible. Wherever the copper sulphate was omitted and the arsenate-soap-lime mixture was used, no injury resulted.

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[1] An appreciable difference was noticed in the length of time required to "wet" the clusters of different varieties. Beginning with Niagaras, which were most readily wet, the other varieties followed in about this order: Catawbas, Delawares, Ives, and Concords. This difference is apparently closely correlated with the waxy bloom on the grape berries.

The burning was closely related to the thrift of vines, the stage of grape growth when sprays were applied, the weather during and following spray aplications, and the method of mixing materials. Weak vines and those bearing too heavy crops were most seriously burned. Spray applications just before and after bloom caused more injury than later applications. Excessively wet and cloudy weather during and following spray applications appeared to increase burning. When either of the ingredients of Bordeaux was added to the other without being diluted, increased burning resulted.

From the above observations it is concluded that Bordeaux mixture should not be used in the arsenate of lead-soap combination on the Ives variety at any time and that in applying the combination with Bordeaux to Concords and Catawbas the above factors influencing foliage injury should be kept in mind. The arsenate of lead-soap-lime mixture was safe wherever used, even on the Ives variety. The injury from spray materials appears to be cumulative from season to season. The combinations of spray materials and factors influencing grape foliage injury warrant further experimentation.

Dusting for Control of Grape-Berry Moth.

Much interest is centering in the application of insecticides and fungicides in dust form as compared with the liquid application. In an attempt to avoid all spray residue on grapes at harvest time, grape-dusting experiments were conducted in 1916, 1917, and 1918. The final infestation in check plats adjacent to the dusted plats was so light as to give inconclusive results except in 1916. The plan of the 1916 experiments and the results recorded are presented in Table IX.

TABLE IX.—*Dusting experiment for control of grape-berry moth, Schonhardt Vineyard, Venice, Ohio, 1916.*

Plat No.	Dust and spray mixtures used and dilutions.	Spray applications.		Counts of infested grapes at harvest, Oct. 13, 1916.					
		3 to 5 days after grapes bloom, June 29.	When second-brood larvæ begin to hatch, Aug. 4.	Number of vines examined.	Number of clusters examined.	Number of grapes examined.	Number of clusters infested.	Number of grapes infested.	Percentage of grapes infested.
1	Arsenate of lead powder, 2½ pounds to 50 gallons; Bordeaux, 3-3-50; laundry soap, 2 pounds to 50 gallons. Liquid application	X							
	Dust mixture, arsenate of lead powder 10 per cent, hydrated lime 90 per cent		X	8	211	6,330	211	2,978	47.04
2	Arsenate of lead powder, 2½ pounds to 50 gallons; Bordeaux, 3-3-50; laundry soap, 2 pounds to 50 gallons	X	X	6	215	6,450	202	1,194	18.51
3	Check unsprayed			8	239	7,170	239	5,668	79.05

The dust materials were applied with a small hand duster and the liquids with a gasoline power sprayer. In each case the application was made from either side of each row and a thorough covering of foliage and fruit effected. The dust materials adhered to the grape foliage fairly satisfactorily but did not adhere well to the smooth surface of the grape berries. No rain fell from the time of the application until August 11 when a light shower occurred. When the vines were examined on August 19 only a trace of the dust material was in evidence on the foliage or fruit, while the sprayed fruit was well covered with spray material. It required 40 pounds of dust material to dust 46 thrifty Catawba vines. At this rate and with the vines set 900 to the acre as is the practice in this section, it would require 783 pounds of material per acre. No doubt this would be materially reduced if a power machine were used for the dusting. If but half as much material were required per acre the amount of arsenical would be from 6 to 7 times as great as when applied in liquid form at the rate of 1½ pounds of arsenate of lead powder to 50 gallons of spray and the liquid applied at the rate of 200 gallons per acre. The writers feel that the dust would have to be applied much more frequently than the liquid to be effective for berry moth control. This method of application might be satisfactory for treating small home grape arbors when applied frequently.

Spray Residue on Grapes at Harvest Time.

Throughout these investigations records were kept on the comparative amounts of spray residue on the grapes at harvest time. In all cases where the spray application shown as the third (fig. 1) was used in early August the fruit was heavily coated with spray material at harvest time. In nearly all cases where the combination of first and second sprays was used, and spraying completed by July 25, there was not sufficient spray residue at harvest time to affect the marketing of the grapes in baskets for table use. When either the first or second application was used alone the residue was lighter than when both were used. Slightly more residue resulted on the plats sprayed with arsenate of lead at the rate of 2½ pounds than on those sprayed with the same material at the rate of 1½ pounds to 50 gallons. No difference could be seen between the fruit from plats on which Bordeaux was included and those on which lime, 2 pounds to 50 gallons, was substituted for it. Slightly less residue was present on the plats sprayed with arsenate of calcium than on those sprayed with arsenate of lead where the comparison of material was on the basis of arsenical content. In one plat where these materials were mixed in the proportion of arsenate of calcium 9 ounces to arsenate of lead 5 ounces, the amount of residue was greater than where arsenate of calcium was used alone and less than where arsenate of lead was used alone.

Summary of Results with Spray Materials.

Arsenicals.—Arsenate of lead powder at the rate of 1½ pounds to 50 gallons proved adequate for commercial control of the grape-berry moth in the average case. Arsenate of calcium proved almost equally as efficient as arsenate of lead when compared on the basis of arsenical content and has the additional advantage of leaving less residue at harvest time.

Spreaders and adhesives.—Resin fish-oil soap at the rate of 1 pound to 50 gallons possessed all the qualities desired and required 33 per cent less spray material than laundry soap and 86 per cent less than soft soap, to wet the grape clusters on an equal area of vineyard.

Spray combinations.—The mixture of arsenate of lead and soap with Bordeaux should be used with care on Catawba and Concord varieties. The Bordeaux mixture should be omitted on the Ives variety. Stone lime at the rate of 2 pounds to 50 gallons should be added to the arsenate of lead-soap combination when Bordeaux mixture is omitted.

Dust mixtures.—The dust mixture of arsenate of lead and hydrated lime did not adhere to the grape clusters as well as the liquid sprays. The dust material was only partially effective for the control of the grape-berry moth.

Spray residues.—Objectionable residues do not result when the first and second spray applications are used with care. A spray application in August with the materials necessary for berry-moth control will leave a residue which will bar the fruit from the basket market.

COST OF TRAILER SPRAYING.

Because of the fan training system it was necessary, when spraying, to drive between each two rows of grapes. Each rodman sprayed but one side of one row at a time. In the Chautauqua-Erie belt it was found possible for a man to spray both sides of a row as he went, but there appears to be little gain in time by the latter method. In all of the experimental work it was found possible to mix and apply 6 tank loads of 150 gallons each or a total of 900 gallons in 9 working hours. This amount of material covered from 3 to 8 acres, depending on local conditions, and averaged about 5 acres. About one-half more material was required for the second application than for the first. Where the third application was made on plats that had received the second, the amount was about the same as for the first application, but where the second had not been applied slightly more material was required for this third application than for the second application in adjoining plats. This difference is accounted for by the fact that the material from the second application remains on the grapes and overcomes the waxy bloom, thereby allowing quick wetting.

The following comparisons of single-nozzle, double-nozzle, and spray-guns for use in trailer spraying were made:

TABLE X.—*Experiments with single and double nozzles and spray guns for use in trailer spraying of grapes. E. Dunning's vineyard, Avon Lake, Ohio, 1918.*

[First spray application for grape-berry moth control, June 19.]

Plat No.	Number nozzles per rod.	Nozzle apertures.	Pressure per square inch.	Time to spray 150 gallons.	Number rows sprayed.	Percentage of time saved.	Percentage of material saved.
		Inches.	*Pounds.*	*Minutes.*			
1	1	$\frac{1}{16}$	175	64	14	0	0
2	2	$\frac{1}{32}$	175	50	16	21.8	14.2
3	(1)	$\frac{1}{8}$	200	38	16	40.6	14.2

1 Spray guns, 1 to each hose line.

In Table X it is seen that two medium nozzles per rod saved 21 per cent in time and 14 per cent in materials as compared with one large nozzle. Spray guns saved 40 per cent in time and used no more material than two nozzles per rod, but an angle at the nozzle end of a rod is a necessity for thorough covering of the grape clusters. The writers believe that for the average vineyard two disk nozzles, at an angle of 45°, to each rod, with $\frac{1}{16}$-inch apertures and a pressure of 175 pounds, will be found most satisfactory.

Materials and labor vary so greatly from season to season and in local sections that figures as to the cost of spraying are of little value. The statement can be made that an average of about 5 acres of thrifty vineyards can be sprayed by two men with a team in a day and will require from 100 to 250 gallons, averaging 147 gallons (Tables I and II) per acre for the first application, and from 160 to 300, with an average of 224 gallons per acre, for the second application.

CONCLUSIONS.

The grape-berry moth has been a more general pest in northern Ohio than in other commercial grape sections because of the following conditions: (1) Production of the late maturing Catawba variety, (2) cultural methods favorable to successful wintering of the insect, (3) harvesting methods which leave the insect in the vineyards, (4) a grape training system which prevents spray materials from reaching the clusters when applied with set nozzles.

Spray schedule.—The combination of first and second spray applications is adequate for control on the principal varieties of grapes grown in northern Ohio and when carefully applied leaves the fruit suitable for the basket market.

Spray materials.—A combination of arsenate of lead powder 1½ pounds to 50 gallons and resin fish-oil soap 1 pound to 50 gallons, in Bordeaux mixture or with stone lime 2 pounds to 50 gallons, may be used for spraying Concords and Catawbas. Copper sulphate should not be used in the above mixture for Ives variety. Arsenate of calcium, commercial powder, proved almost as efficient as arsenate of lead for grape-berry moth control. Dust mixtures do not adhere to the grape berries as well as liquid sprays but may be used on small home grape arbors if applied frequently.

Spray residues.—The grapes will be practically free from spray residue if the schedule recommended is used according to directions.

Spray method.—The trailer method only was used, and a trailer provided with a short rod and two angle nozzles proved most satisfactory in most vineyards.

RECOMMENDATIONS.

When possible, vineyards should be placed in condition for winter at the end of the cultivation season in July and left without further cultivation until spring; this practice is designed to increase the winter mortality of the grape-berry moth pupæ.

Number of spray applications.—For general practice for grape-berry moth control in northern Ohio two spray applications should be made.

Time.—The first application should begin 3 to 5 days after grapes set and the second should begin when the grapes touch in the clusters. This second application will usually come 3 to 4 weeks after the first.

Method.—Where the berry moth is a major pest the trailer method of spraying is the only one that will give complete control.

Materials.—Arsenate of lead, at the rate of 1½ pounds of powder or 3 pounds of paste to 50 gallons, as the active killing agent, with resin fish-oil soap, at the rate of 1 pound to 50 gallons, for a spreader and adhesive, used either in Bordeaux mixture or with 2 pounds of freshly slaked lime to each 50 gallons, has proved the most consistent combination tried. Bordeaux mixture should not be used on the Ives variety of grapes in northern Ohio because of the danger of injury to the foliage. Amounts of material should be great enough to allow the covering of all clusters with a thin, smooth film of spray material.

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 838

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER June 5. 1920

CYPRESS BARK SCALE.[1]

By F. B. Herbert,
Scientific Assistant, Forest Insect Investigations.

CONTENTS.

ECONOMIC IMPORTANCE.

The Monterey cypress (*Cupressus macrocarpa* Hartw.) is one of the most popular shade and ornamental trees in California. It is planted separately or in hedgerows and often trimmed to formal shapes. Due to its thick, spreading habits it makes a good windbreak where it is planted in exposed areas. It is used especially along the coast and in the sandy citrus areas of San Bernardino County. It is also cultivated as an ornamental tree in many other parts of the world.

The cypress bark scale infests a large percentage of these trees in California, causing a great deal of injury, particularly to the thickly planted hedgerows (Pl. I, figs. 1, 2) and windbreaks. In the San Francisco Bay region it ranks first among the pests of the

[1] *Ehrhornia cupressi* (Ehrhorn). Order Hemiptera, suborder Homoptera, family Coccidae.

NOTE.—An investigation of the injury to cypress trees in California was taken up by the writer, at the suggestion of Dr. A. D. Hopkins, Forest Entomologist, in November, 1916. An examination made of these trees in the vicinity of the Los Gatos laboratory disclosed the main cause of the injury to be the cypress bark scale, *Ehrhornia cupressi* (Ehrhorn). This bulletin contains a record of studies of its history, biology, importance, and control made during this investigation.

The writer wishes to acknowledge the assistance of Dr. A. D. Hopkins, Forest Entomologist; Mr. H. E. Burke, Specialist in Forest Entomology; Prof. R. W. Doane and Mr. G. F. Ferris, of the Stanford University Department of Entomology; and Mr. George P. Gray, of the University of California Insecticide Laboratory, all of whom offered helpful suggestions during this study. Mr. R. D. Hartman assisted in the control experiments.

Monterey cypress. The insect is extremely difficult to control—a fact which makes it a very disagreeable and harmful pest.

HISTORY.

The cypress bark scale was first described in 1911 as *Sphaerococcus cupressi* by Mr. E. M. Ehrhorn [1] who collected it at Niles and San Jose, Calif., as early as 1903, and at Belvedere, Calif., in 1908, in the bark crevices of Monterey cypress. The next mention of this insect was in the report of the Selby Smelter Commission in 1915, when Mr. J. W. Blankinship [2] and Prof. R. W. Doane [2] reported it as one of the factors causing the death and dilapidation of the Monterey cypress in the Selby smoke zone. In October, 1918, Mr. G. F. Ferris,[3] with the writer's approval, erected a new genus, Ehrhornia, for this species, for it certainly was not a Sphaerococcus. Although an important shade-tree pest, no discussion of this insect has appeared in print otherwise, except for a short note by the writer [4] on its damage and distribution.

This coccid has no synonyms, having been listed under the name *Sphaerococcus cupressi* until the new genus, Ehrhornia, was erected in 1918, with *cupressi* as the type.

NATIVE HOST PLANT.

This scale insect could not be found at Cypress Point or Point Lobos, Calif., the only localities where the Monterey cypress is native, which showed quite conclusively that this tree was not the native host.

On November 9, 1917, the cypress bark scale was found infesting some planted trees of Arizona cypress (*Cupressus arizonica*) at San Jose, Calif., although it has not at the present writing been found on the native cypress in Arizona.

On December 6, 1917, this insect was found by the writer infesting one incense cedar (*Libocedrus decurrens*), and later several more trees, on the Stanford University campus. Later, the native incense cedars at Placerville, Calif., were examined. A number of them were found infested. They were several miles from any planted cypresses, which, moreover, were not infested.

Later, the cypress bark scale was found upon incense cedar at Ashland, Oreg., by Mr. Albert Wagner, of the United States Bureau of Entomology; at Crockers, Calif., by Mr. G. F. Ferris; and at

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[1] Ehrhorn, E. M. New Coccidæ with notes on other species. *In* Can. Ent., v. 43, no. 8, p. 275–280. (Figs. 3, 3a, b, c.) 1911.

[2] Holmes, J. A., Franklin, E. C., Gould, R. A. Report of the Selby Smelter Commission. U. S. Dept. Int., Bur. of Mines, Bul. 98, p. 381–597; 428–450. 1915.

[3] Ferris, G. F. Notes on Coccidæ II. *In* Can. Ent. v. 50, no. 10, p. 323–332. 1916.

[4] Monthly Letter of the Bureau of Entomology, U. S. Dept. Agr., no. 46, p. 5. February, 1918.

Stirling City and Giant Forest, Calif., by the writer. These localities are all from 75 to 150 miles apart and from 5 to 50 miles distant from any planted cypress. This seems to indicate that the incense cedar is the native host for this scale insect.

Mr. G. F. Ferris reports finding this scale insect upon herbarium specimens of Guadalupe cypress (*C. guadalupensis*) in the Stanford University herbarium, collected on Guadalupe Island, Mexico. It is impossible at present to state whether this is one of the native hosts of the scale, or whether the scale has been carried there from the mainland.

DISTRIBUTION AND SPREAD.

Incense cedar, the original host plant of the cypress bark scale, occurs in California, Oregon, western Nevada, and Lower California. The majority of these trees are found in the Sierra Nevada and northern coast range mountains of California, and in the Siskiyou, southern coast range, and Cascade Mountains of Oregon.

The cypress bark scale has been found at four widely separated points in the Sierra Nevadas (Stirling City, Placerville, Crockers, and Giant Forest, Calif.) and at one point in the Siskiyou Mountains (Ashland, Oreg.), which indicates that the scale undoubtedly occurs throughout the major portion of the range of the original host.

From this host the scale insect has spread to planted incense cedars and cypresses in the more thickly populated regions of the State. Two probable methods of distribution are suggested.

The cypress bark scale has been found to thrive on very young trees. Incense cedar seedlings occasionally are brought down from the Sierra Nevadas by tourists to plant in their own yards, and it is quite possible that the scale was carried to the valley on some of these trees. Rustic incense cedar is also transported from the Sierra Nevadas to be used quite extensively for pergolas and porch pillars. Ordinarily this would be done during the summer, which is the reproductive period for the scale insect. As the females can live for some time on green logs, it would be very easy for the young larvæ, hatched en route or after the logs have reached their destination, to attach themselves to near-by cypress trees, and thus start a heavy infestation in a new location.

From these original points of infestation the pest has spread through large areas. This has been accomplished for short distances by the usual agencies of wind, birds, insects, etc., and for longer distances by the shipment of infested nursery stock. The insect has been found by the writer infesting cypress seedlings in nurseries. Close planting of shade trees, hedges, and windbreaks undoubtedly aids in its rapid spread by natural means.

The scale insect, besides being distributed on the incense cedar, has now spread until it occurs on a large percentage of the cypress trees and hedges in almost every locality about San Francisco Bay, particularly on the San Francisco Peninsula, in the Santa Clara and Livermore Valleys, and north of the bay in Solano, Marin, and Sonoma Counties. It has been found in one locality, Riverside, in southern California, where a great many trees are planted for windbreaks. It is also to be found on Guadalupe Island, Mexico, as it was recently taken from herbarium specimens of Guadalupe cypress collected on this island.

The accompanying map (fig. 1) indicates the localities in which the cypress bark scale has been found to date, as well as the range of incense cedar and Monterey cypress. There are many localities within the range of cypress and incense cedar, which the writer has not yet visited, in which the scale insect will probably be found, when investigated. In all probability it eventually will infest all planted cypresses unless radical measures of control are adopted.

Since it has been found that the cypress bark scale can live on Arizona cypress, it is possible that it may spread to that host in Arizona and Mexico, or it may even be able to adapt itself to closely related hosts and spread throughout the country.

INJURY.

Injury to the tree is caused by the myriads of insects which are to be found in every crack and crevice of the trunk, branches, and twigs, each sucking out the plant juice through its long thread-like mouth parts. Under each scale may be found a small brown ring in the cambium, showing the tissue killed by each individual.

There is no secretion of honeydew, except for a small amount by the young larvæ, and only a slight formation of black sooty fungus about these insects, but a secretion of white cottony wax protruding from the bark crevices and covering the twigs gives abundant evidence of their presence (Pl. II).

First a limb or two on an infested cypress turns yellow, then red or brown, giving the tree (Pl. III) a scraggy appearance. This appearance often starts near the top of the tree and works down toward the center, or perhaps spreads from one limb to the rest until the whole tree is dead. Quite often the trees are dug up or felled before this final stage is reached; others are left to mar the landscape until they rot and fall.

In hedges, yellow and red spots appear, which increase finally to large proportions, leaving wide gaps of dead material which eventually destroy the beauty of whole hedges. One hedge in Livermore, nearly a half mile long, was infested and dead or dying

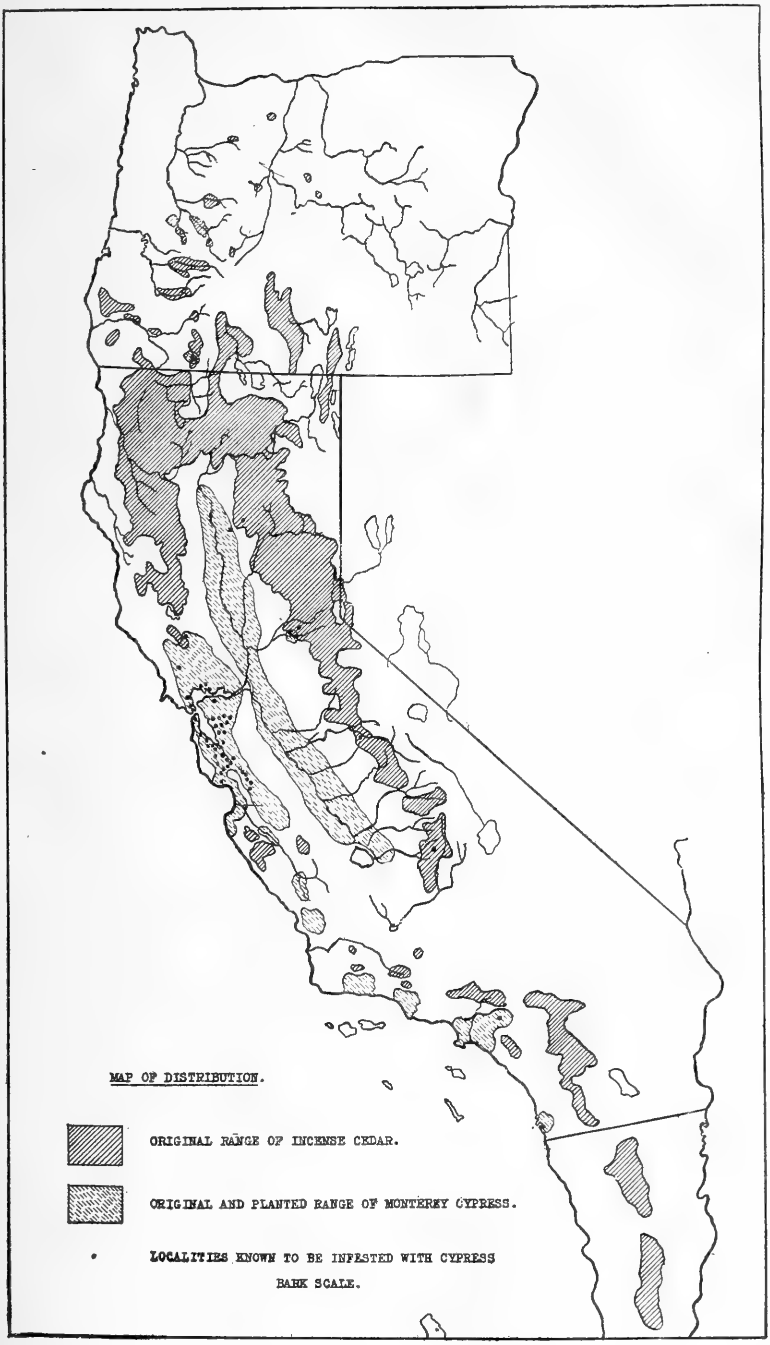


FIG. 1.—Map of distribution of the cypress bark scale.

for its full length. Young hedges but 3 or 4 years old have been found infested and some of the trees dead even before the hedge has become of any particular use or ornament.

Windbreaks with an opening here and there, caused by the death of a tree or group of trees, are not nearly as efficient as they would be otherwise.

In the drier regions of the State the injury is more apparent than in the fog belt, where the tree seems to be much more thrifty. In the former regions the cypress is not a long-lived tree, and when infested death is hastened considerably.

Trees occasionally are found that are heavily infested, yet quite normal in appearance. It is believed that such trees have only recently been infested, and will eventually show the effects of this slow-working insect.

In some localities in central California there is hardly a respectable row of trees or hedge left to greet the eye. At Los Gatos many trees have died and very few remain which are not now infested. About San Jose, Livermore, Benicia, etc., there are also heavy infestations.

INJURY IN THE SELBY SMOKE ZONE.

The "Selby smoke zone" is an area extending for nearly 10 miles along the Carquinez Strait, between San Pablo and Suisun Bays. The Selby smelter is located on the south side and at the west end of this strait. The prevailing winds are from the west and southwest, thus blowing the smelter smoke across the strait onto the territory between Vallejo and Benicia.

In this area there has been considerable complaint of damage done to different trees and plants by this smoke. Many of the Monterey cypresses in this territory are dead or dying. Examination of these trees and plants by specialists of the Selby Smelter Commission has proved that insects and fungi are responsible for part, at least, of the damage.

The writer has examined Monterey cypresses in certain parts of the smoke zone and has found the scale insect abundant. In the Benicia Cemetery, practically 100 per cent of the trees were found infested and a large percentage were dead or dying. According to Prof. Doane, this cemetery, although infested in 1913, contained but few dying trees. Probably at that time the infestation was rather recent, but has gained headway since.

In the writer's judgment, the cypress bark scale is the main factor causing the unsightly and dying condition of these trees. One need only see the condition of the cypresses in the Livermore and Santa Clara Valleys to reach this conclusion.

ASSOCIATED INSECTS.

The cypress bark scale is by no means the only enemy of the cypress. The cypress barkbeetles (*Phloeosinus cupressi* Hopk. and *P. cristatus* Lec.) are important primary insects, causing the death of a considerable number of trees, and perhaps ranking first among the pests of the cypress in California, considering the State as a whole. In the San Francisco Bay region they must, however, take a place second to the scale in point of damage done.

Many people throughout the State have considered the beetles as the only enemies of the cypress, and, when noting the death of a tree, have taken it for granted that the beetles were the primary cause, without bothering to investigate properly. The entire foliage of trees killed by the beetles turns first yellow, then brown, and is much more conspicuous than the foliage of a tree being killed by inches by the scale insect. The presence of the beetles is also more easily detected.

At times the beetles have been found working independently of other insects, and killing trees. For example, at San Carlos, on the San Francisco Peninsula, the beetles have been killing several trees per year for a number of years. In the spring of 1918 they were found entering the green trunks of live trees and girdling them. Other trees showing the work of Phloeosinus, dead one or two years, stood near by. The recently attacked and the unattacked trees were apparently very healthy.

The beetles are often secondary pests, entering trees well infested and weakened by the scale insect. At Martinez, Calif., in January, 1918, a row of 12 trees was heavily infested with the scale insect. Three of these had been recently killed by barkbeetles. On Alum Rock Avenue, San Jose, Calif., there is a long double row of cypresses, all of which are heavily infested with the cypress bark scale and practically all of which have a sickly appearance. Here the barkbeetles attack an occasional tree, or a section thereof, and hasten its death. They also impair the beauty of the trees by entering into the center of small twigs and weakening them, so that the wind breaks them off. When gathered together, the twigs from one tree formed a pile $2\frac{1}{2}$ feet high and nearly as broad. There were also many twigs still hanging broken in the tree. The injury to cypresses by these beetles will be treated separately in a later paper.

Three species of mealybugs, *Pseudococcus ryani* Coq., *P. sequoiae* (Coleman), and *P. cupressicolus* Ferris, also infest cypresses and occasionally do some damage.

Other associated scale insects are *Xylococcus macrocarpae* Coleman, *Lecanium corni* Bouché, *Diaspis carueli* Targ., *Aspidiotus* *hederae* (Vallot), and *Aspidiotus ehrhorni* Coleman. None of these have been noted doing any considerable damage.

Still other associated insects of various orders are: *Phymatodes nitidus* Lec., *Atimia confusa* Say, *Trachykele blondeli* Mars., the cypress moth (*Argyresthia cupressella* Wals.), the cypress cone-borer (*Cydia cupressana* Kear.), a horn-tail wasp (*Sirex californicus* Ashm.), the arborvitæ plant-louse (*Lachniella tujafilina* Del Guer.), and an undetermined tussock moth.

FOOD PLANTS.

The known food plants of the cypress bark scale are: Monterey cypress (*Cupressus macrocarpa* Hartw.), Arizona cypress (*C. arizonica* Greene), Guadalupe cypress (*C. guadalupensis* Wats.), and incense cedar (*Libocedrus decurrens* Torr.). On one other tree, a deodar cedar (*Cedrus deodara* Loud.), at Santa Rosa, Calif., a dead male was found in its cocoon.

It seems strange that the scale insect should not occur on all species of cypress if it will infest two trees as different as Monterey cypress and incense cedar, yet Italian and Oriental cypresses, two varieties of *Cupressus sempervirens*, are immune to the attack of this insect. They have been found in many instances in close proximity to infested Monterey cypresses and entirely free from the scale insect. In one case, in the Benicia Cemetery, 27 cypresses formed a square about a plot. Two-thirds of these were Monterey cypresses, with every third tree an Italian cypress, touching a Monterey cypress on each side. Every Monterey cypress was infested and dead or dying, while not a scale could be found on the Italian cypresses.

Specimens of Himalayan cypress (*C. torulosa* Don.), Macnab cypress (*C. macnabiana* Murray), funeral cypress (*C. funebris* Endl.), Sargent cypress (*C. sargentii* Jepson), and Port Orford cedar (*Chamaecyparis lawsoniana* (Murr.) Parl.) have been examined, although not in large numbers, within the infested areas, and no cypress bark scales could be found upon them.

DESCRIPTION.[1]

THE EGG.

Egg (Pl. IV, *A*), immediately after being deposited, regularly oval, smooth, and shiny, of a transparent pale yellow color, with eyes of embryo visible through membrane as two dark spots near one end. Average length of seven eggs 0.34; mm.; width 0.14.

LARVA.

FIRST INSTAR.

Young larvæ (Pl. IV, *B*) of both sexes alike. Pale yellow in color, with long, flat, oval bodies 0.43 mm. in length, 0.20 mm. in width. Antennæ (Pl. V,

[1] The following detailed description of all stages from the egg to adult, both male and female, were made from living and freshly mounted material collected during the study of the cypress bark scale.

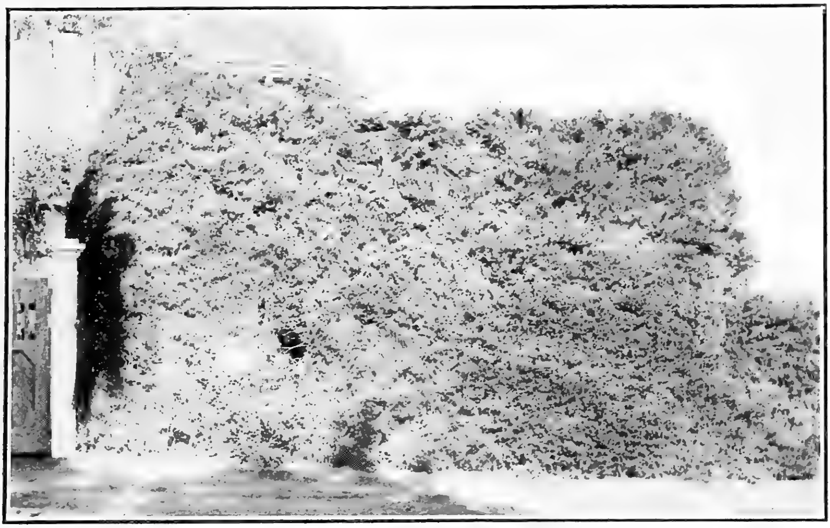


FIG. 1.—A TALL MONTEREY CYPRESS HEDGE, SHOWING MANY DEAD SPOTS CAUSED BY THE CYPRESS BARK SCALE.

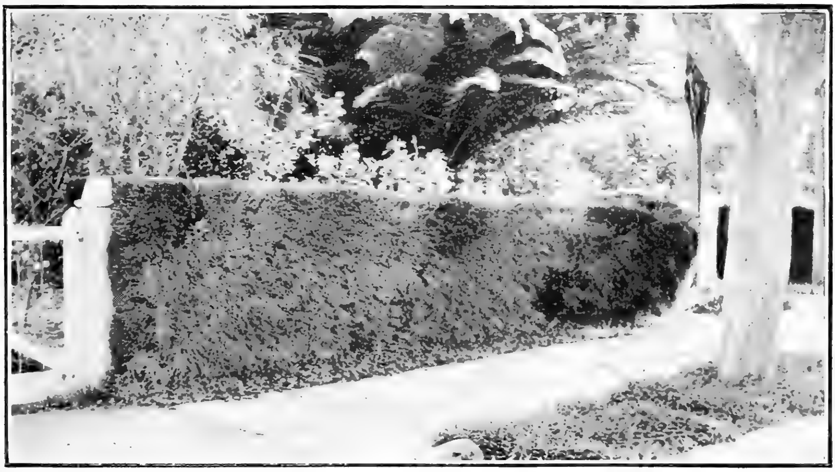


FIG. 2.—A MONTEREY CYPRESS HEDGE KILLED BY THE CYPRESS BARK SCALE.

THE CYPRESS BARK SCALE.

FIG. 1.—CHARACTERISTIC INFESTATION ON MONTEREY CYPRESS TWIG, SHOWING THE COTTONY EXCRETIONS OF THE CYPRESS BARK SCALE. × 0.4.

FIG. 2.—CHARACTERISTIC INFESTATION ON THE BARK, THE COTTONY EXCRETIONS OF THE CYPRESS BARK SCALE PROTRUDING FROM THE CREVICES. × 2.

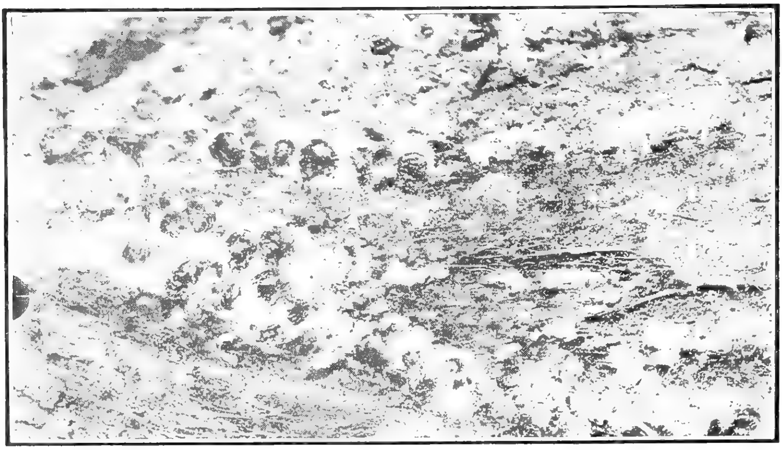


FIG. 3.—THE DRY OUTER PORTIONS OF THE BARK REMOVED, REVEALING THE FEMALES OF THE CYPRESS BARK SCALE UNDERNEATH. × 4.

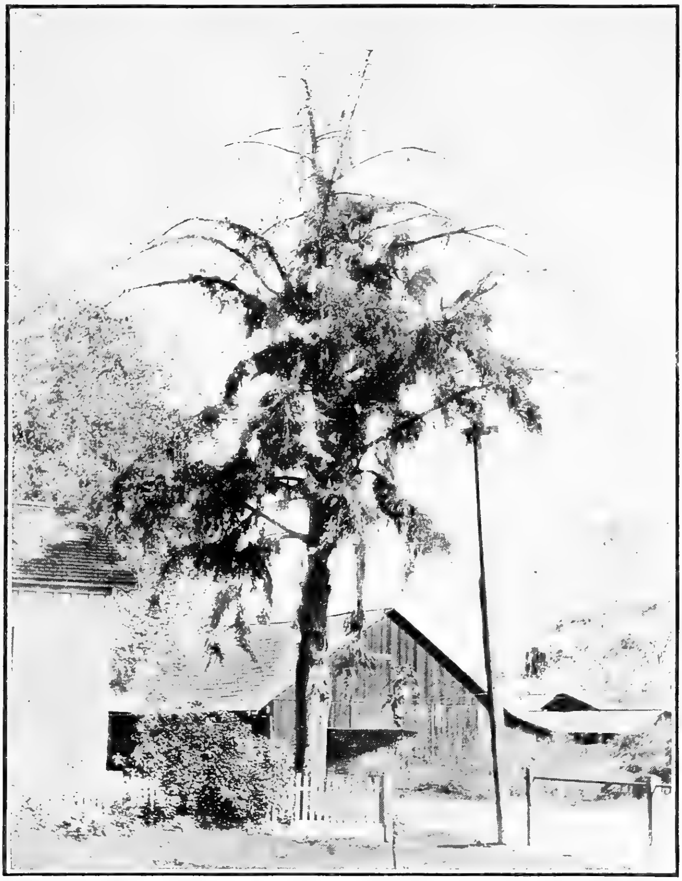
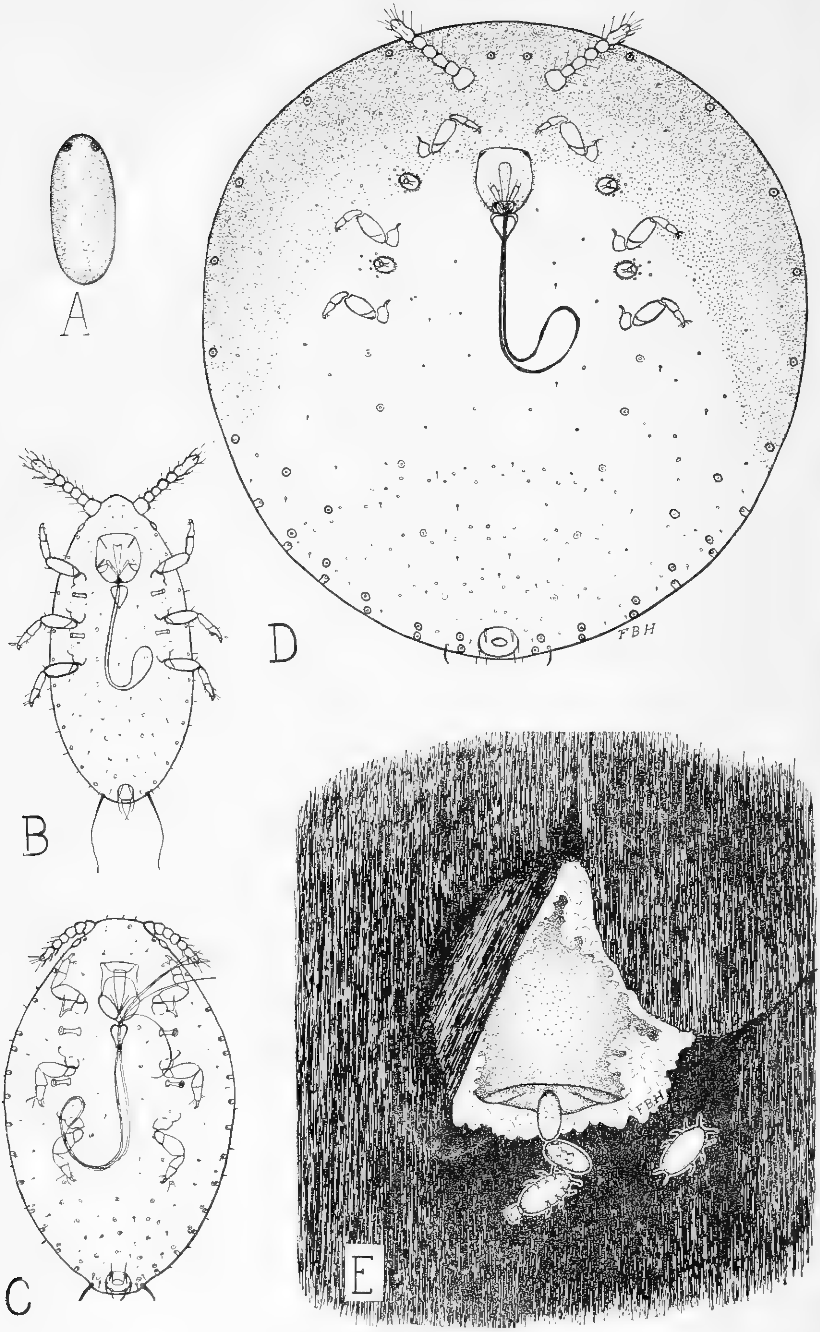


FIG. I.—A MONTEREY CYPRESS WHICH IS NEARLY DEAD FROM THE WORK OF THE CYPRESS BARK SCALE.

FIG. 2.—A ROW OF MONTEREY CYPRESSES, ALL OF WHICH ARE PRACTICALLY DEAD FROM A CYPRESS BARK SCALE INFESTATION.

THE CYPRESS BARK SCALE.



THE CYPRESS BARK SCALE.

A, Egg (× 55); *B*, larva, first instar (× 85); *C*, female larva, second instar (× 55); *D*, adult female (× 55); *E*, portion of bark removed, showing adult female depositing eggs, the eggs hatching, and the larva crawling away.

A, 2) six-segmented, first segment broadest, sixth longest. Normal antennal formula as follows: 6, 1, (2, 4, 3, 5). Joints 2, 3, 4, 5 subequal and variable, thus causing various formulæ. Antennæ rather hairy. Fifth segment bearing one broad spine, while four occur on sixth segment. Eyes marginal, set a short distance behind antennæ. Legs rather short and stout. Tarsus slightly longer than tibia, the two combined slightly longer than femur and trochanter combined. Legs rather hairy, tarsi bearing four knobbed digitules. Usual coccid sucking mouthparts present. About 26 trilocular pores set rather regularly about margin and two longitudinal rows of the same type on dorsum of insect. Caudal setæ (Pl. V, *B*, 1) prominent, rather stout, and about 140 μ long; borne on small inconspicuous anal lobes. Anal ring bearing six setæ, noticeably longer than in later stages. A number of short spines scattered over body.

SECOND INSTAR.

Immediately after the first molt some differences between the sexes can be detected under the microscope. Toward the end of the second stage an external difference can be observed in the shape, the female being broader than the male.

Female larva (Pl. IV, *C*) about 0.84 mm. long and 0.51 mm. wide, oval in outline, yellowish brown in color. Legs and eyes similar to those of first-stage larva. Antennæ very similar except that sixth segment bears only two broad spines. Caudal setæ (Pl. V, *B*, 3) much shorter, being only 37 μ long. Anal ring still bearing six hairs, also shorter than in preceding stage. A larger number of tubular wax ducts, varying from 40 to 75, to be found on dorsum, particularly abdomen, and on lateral margin. Also a number of trilocular pores and small spines scattered over body.

Male larva (Pl. VI, *A*) about the same length but narrower than female; 0.85 mm. long by 0.43 mm. wide. Color yellowish. Caudal setæ twice as long as those of female, half as long as those of first-instar larva, 75μ. Six anal hairs, in length equaling diameter of anal ring; longer than those of second-stage female, but shorter than those of first-stage larva. Pores of male larva very inconspicuous (Pl. V, *D*, 2), smaller than those of female. Small quinquelocular type pores scattered over both dorsum and venter of body. Small tubular ducts found mostly on margin. Small spines also present.

ADULT FEMALE, THIRD INSTAR.

Body (Pl. IV, *D*) nearly circular and quite convex, the width exceeding the depth and the length exceeding the width. Average length 1.45 mm., average width 1.35 mm. General color reddish brown. Anterior half of body quite heavily chitinized, particularly on margin. Derm smooth.

Antennæ (Pl. V, *A*, 3) no longer marginal, but occurring on ventral side of body, six-segmented, slightly longer, averaging 144 μ, but similar to those of second-instar larva, bearing only two of the four spines found on sixth segment of first-instar larva. As in larva antennal formula varying considerably, of practically no value. Average formula as follows: 6, 1, 3, (5, 2, 4). Eyes lacking.

Legs (Pl. V, *C*, 1) short and stout. Tibia and tarsus (Pl. V, *C*, 2) subequal, being together slightly shorter than trochanter and femur combined. Leg bearing a few hairs and tarsus bearing four knobbed digitules. Usual coccid mouthparts present. Large tubular ducts (Pl. V, *D*, 1) occurring on margin and dorsum of body. Small trilocular pores and fine spines scattered over body, particularly on abdomen. Anal ring (Pl. V, *B*, 4) occurring on ventral side of body, small, simple, and with six small setæ or hairs. A pair of small caudal setæ one on each side of anus. Anal lobes absent.

MALE PREPUPA.

With the second molt, the male larva assumes the form of a partly developed pupa, called the prepupa (Pl. VI, *B*). Form elongate oval; length 0.93 mm., width 0.50 mm. Color pale glassy brown, eyes black. Antennæ short, reaching to base of anterior legs and now indistinctly 10 segmented. Wing pads very short, curving under body to middle pair of legs. Anterior legs reaching forward, covering "face," the two posterior pairs lying against abdomen. Mouth parts wanting. Segmentation of thorax indistinct. Prepupa incapable of movement, except in abdominal segments and anterior legs, which may be feebly moved.

MALE PUPA.

With the third molt, the male becomes a true pupa (Pl. VI, *C*), greatly resembling the adult male, except for the lack of anal wax filaments, and the possession of wing pads instead of wings. General color light brown, head and large, conspicuous wing pads paler, legs and antennæ glassy white, eyes black. Antennæ distinctly 10-segmented and longer, reaching to base of middle pair of legs. Wing pads appressed to sides of body and extending posteriorly to second abdominal segment. Legs capable of some movement, anterior pair extending beyond the head; middle femora placed transverse to and extending beyond lateral margin of body, rear pair inclining posteriorly. The larval eyes have disappeared, and have been replaced by one dorsal and one ventral pair. Mouth parts replaced by an approximate pair of eyes. Length 0.95 mm.; width 0.45 mm.

ADULT MALE.

(Pl. VI, *D, E.*)

Measurements of average adult male: Length of body (exclusive of appendages) 0.75 mm.; antennæ 0.55 mm.; wax filaments 0.93 mm.; wing expanse 2.15 mm. General color light brown with paler brown appendages.

Antennæ (Pl. V. *A*, 1) 10-segmented, rather hairy, first joint short and broad, second rather long and broad, others more slender. Antennal formula: 3, 4, 5, 6, 7, 8, 9 (10, 2), 1. Legs rather long, slender, and somewhat hairy. Wings transparent white, slightly iridescent and pubescent. A veinlike thickening, beginning at base of wing, branching near base, one branch paralleling costal margin, the other extending toward anal distal margin. Club-shaped halteres each bearing a hook, which catches in a pocket on anal margin of wing. Abdomen terminating in a short blunt style. Two long white wax filaments arising one on either side of base of style, and extending posteriorly. Each filament arising from a number of pores which surround base of two long slender setæ. Setæ enveloped by wax filaments.

SUMMARY.

As will be noted from the foregoing descriptions, there are three instars (excluding the egg) in the female. These all have legs, which are not used after the larva is attached. All stages are found in crevices or under some covering on the bark and are nearly or completely concealed by the enveloping cottony wax. Newly hatched first-instar larvæ may be found crawling actively over the bark before attachment.

There are five stages in the male. The first two stages are found in similar positions, but the second stage after becoming full grown removes to a dry, secluded spot, where it spins a cocoon in which the remaining transformations take place.

Size and shape are of some use in distinguishing the different stages. The female in its second stage is considerably broader than the male in the second stage, while both are larger than in the first stage. The adult female is more circular than in the preceding stage.

The antennæ of the adult female are slightly longer than the antennæ of second-stage larvæ, while the latter are slightly longer than those of the first-stage larvæ. All are very similar, however, the only distinguishing character being that the first-stage larva possesses two more broad spines on the sixth segment.

The three pairs of legs on each individual are alike, nor is there any difference between the larvæ and the adult female, except a very slight one in the relative lengths of the femur, tibia, and tarsus. Mr. Ehrhorn's figures indicate a difference in the arrangement of the hairs and digitules, which the writer has been unable to detect. There is a very small, scarcely discernible, tooth or "denticle" on the face of the claw in all these stages.

The caudal setæ give good characters for the separation of the different stages. On the first-stage larva they are about 140 microns long; on the second-stage male they are about half as long, 75 microns; those of the second-stage female half as long as the latter, 37 microns; and those of the adult female very much shorter still. The length of the setæ on the anal ring also decreases in the same ratio.

Simple marginal eyes are present in all the larval stages, but not in the adult female. Mouth parts are present in all stages, except in the male prepupa, pupa, and adult.

Four spiracles are present in all the larvæ and the adult female, one behind each of the four forward legs. In the larvæ they appear as simple tubes, and more as large chitinized circles in the adult female.

There are several types of pores found on the derm of the scale insect, which aid in distinguishing the different stages. The small sessile pores are of two types, viz., "trilocular" (Pl. V, *D*, 4) and "quinquelocular" (Pl. V, *D*, 5). The former are more or less triangular and contain three cells or loculi. The quinquelocular pores are nearly circular, but tend to be five-sided, containing ordinarily six loculi, one in the center with five clustered about it. Aside from these there are circular pores communicating with internal ducts. These are short and tubular, bearing at the inner end a cup-shaped depression. All types are presumably capable of secreting wax.

The first-stage larva bears only small pores of the trilocular type. These are arranged in a marginal row on each side of the body and in two longitudinal rows on the dorsum.

On the second-stage female larva are to be found the small trilocular pores scattered over the body, and from 40 to 75 of the large tubular ducts on the margin and dorsum (particularly on the abdomen). The pores of the second-stage male larva are of two types: The small quinquelocular type which are found all over the body, and tubular ducts similar to those of the second-stage female larva, but much smaller and less conspicuous, found mostly on the margin.

The pores and ducts of the adult female are of the trilocular and tubular types, the first scattered over the body and the latter occurring on the margin and dorsum of the body, much the same as in the second-stage female larva.

Small spines (Pl. V, *D*, 3) are present on all these stages. Viewed from above, these spines are likely to have the appearance of circular pores, but can be soon distinguished by altering the focus of the microscope.

LIFE HISTORY AND HABITS.

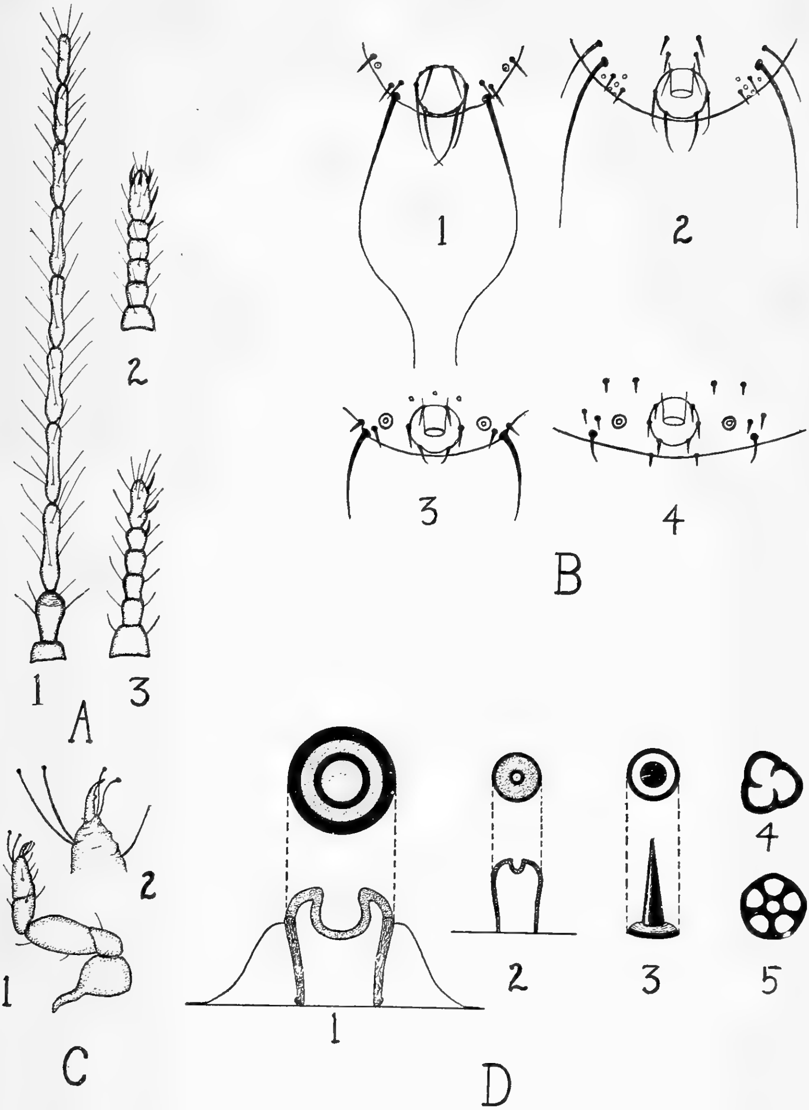
In the early winter adult females are found containing a few eggs. The eggs increase in number and by early spring from 30 to over 100 may be found within each female. During this time the females have increased considerably in size and have become quite heavily chitinized on the anterior half of the body.

OVIPOSITION.

The embryos in the eggs develop within the body of the female until they are about ready to hatch, when they are expelled (Pl. IV, *E*). The female is well surrounded by a cottony secretion, but when oviposition is begun the tip of the abdomen is drawn in, leaving a space in which the eggs may remain until hatched. After hatching, the larvæ are usually able to find an exit between the cotton and the surrounding bark.

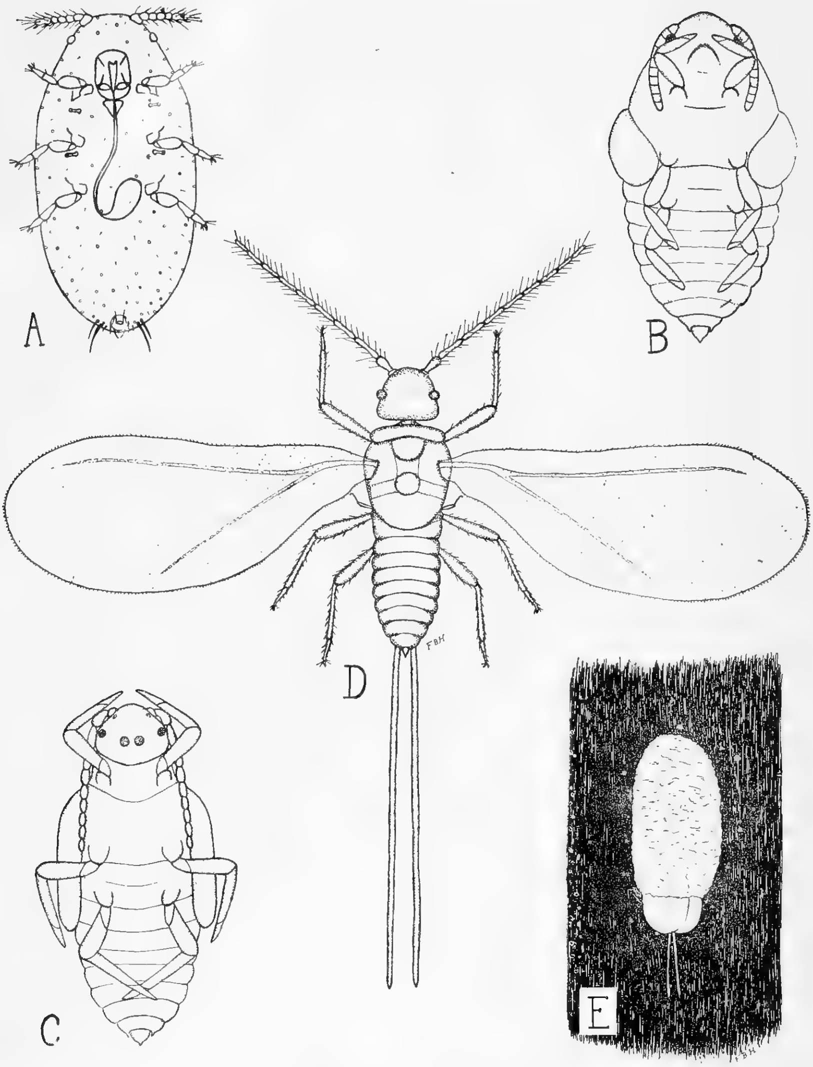
Each female is capable of laying 50 to 100 or more eggs. The greatest number of eggs that has been found within a female at any one time is 105. The eggs are laid slowly, covering a long period of time. They are laid during the warmer part of the day at intervals of 7 to 70 minutes. After laying a series of 5 to 10 eggs, the female ceases oviposition for a day or so and then resumes it.

Most of the embryos in the eggs are deposited tail first, about one-sixth being deposited head first. The head end of the embryo is evidenced by the two black eyes which are visible through the egg membrane. By a series of contractions of the abdomen, the egg is forced out until entirely free from the body of the adult. These eggs are oblong oval when first deposited, but flatten out somewhat before the rupturing of the membrane occurs.



THE CYPRESS BARK SCALE.

A, Antennæ: 1, adult male; 2, first-stage larva; 3, adult female (same as second-stage larva); *B*, Tip of abdomen, showing anal rings and caudal setæ: 1, first-stage larva; 2, second-stage male; 3, second-stage female; 4, adult female; *C:* 1, leg of adult female; 2, tip of tarsus and claw; *D*, Ducts and pores: 1, large pore and tubular duct of adult female; 2, small pore and tubular duct of second-stage male; 3, spine; 4, trilocular pore; 5, quinquelocular pore.



THE CYPRESS BARK SCALE.

A, Male larva, second instar (× 50) (male and female first-instar larvæ are identical); *B*, male prepupa (× 50); *C*, male pupa (× 50); *D*, male adult (× 50); *E*, male adult ready to emerge from cocoon.

About 15 minutes after the eggs are deposited, the embryo starts a series of convulsions and after considerable struggling ruptures the membrane inclosing it. The ruptured membrane is pushed down over the abdomen and the larva, which is usually on its back, begins waving its legs about in the air. It usually takes this larva 20 to 30 minutes to free itself from the membrane, and after exercising its legs for 30 or 40 minutes it finally gets to its feet and crawls away (Pl. IV, *E*). The larva quite often is stuck to the next expelled egg and may be held out in space for some time, but the struggles of one or the other finally allow the feet of the larva to touch foundation, where it soon makes use of them.

MIGRATION.

The larvæ become very active soon after exclusion and begin searching for a suitable spot upon which to locate. The majority of them immediately work down into the bark crevices or under the cottony secretions of the parent females, where they become attached. Some seem more fastidious than others and travel farther in search of newer feeding grounds. Recently hatched larvæ when placed upon favorable young trees do not travel far, and usually settle down after investigating two or three crevices in the bark.

Larvæ placed upon paper were able to travel considerable distances. (See fig. 2.) The average rate of travel for six larvæ was 54.25 cm. per hour, which they were able to maintain for several hours. The greatest distance traveled by one larva was 174 cm. in two hours. One larva, after traveling 124.46 cm. in four hours, apparently put its last efforts into trying to pierce the paper with its proboscis. Table I gives the time, distance, and rate per hour traveled by six cypress bark scale larvæ on black paper for the first few hours of their migration. Black paper was used in order to facilitate following the tiny pale larvæ in their wanderings. When white paper was used the larvæ were soon lost. There seemed to be a slight phototropism in the case of most larvæ, the majority of them finally wandering toward the light.

TABLE I.—*Record of travel of six first-instar larvæ of the cypress bark scale on rather smooth black paper.*

No.	Time.	Distance.	Rate per hour.
	Hours.	*Cm.*	*Cm.*
1	1.5	109.22	72.81
2	2.5	143.51	57.40
3	4.0	124.46	31.11
4	2.0	173.99	86.99
5	2.0	142.24	71.12
6	2.0	66.04	33.02
Average.	2.333	126.577	54.255

Larvæ isolated in vials, immediately after hatching, lived for two and three days. Living for this length of time and traveling at the above rate of speed during only the warmer parts of the day, larvæ could go considerable distances in search of proper food. In this way larvæ are able to migrate from one tree to another in closely planted hedges or windbreaks. During this migratory period, larvæ are also likely to be transported short distances by dropping from high

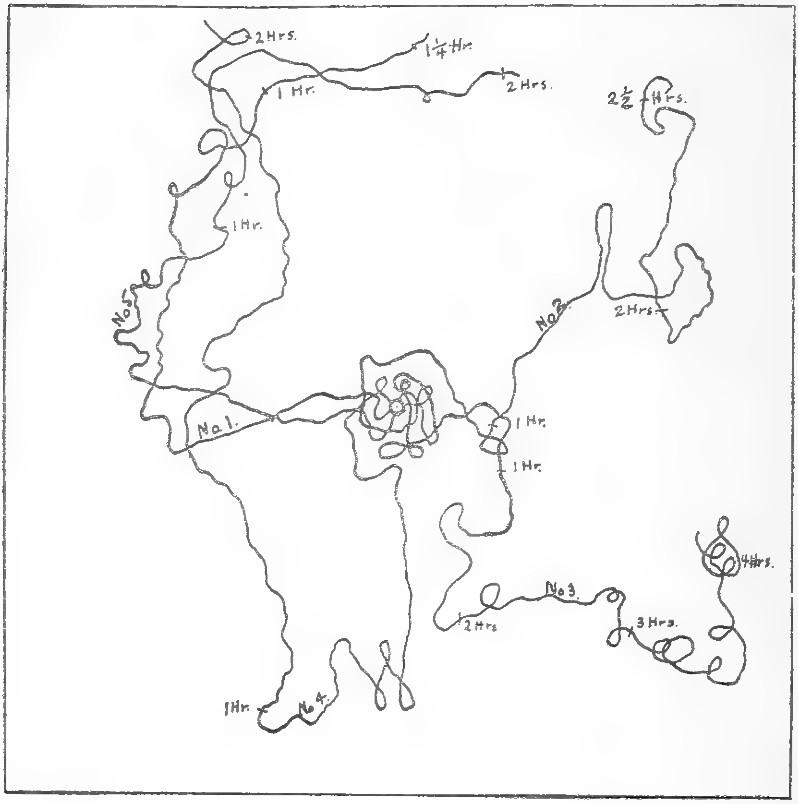


FIG. 2.—Tracings of five first-instar larvæ of the cypress bark scale during migration. Reduced 5½ times. All were started from the same center.

branches and being carried by the wind, and for longer distances by animate agencies, such as insects, birds, and animals.

ATTACHMENT.

As soon as a larva finds a suitable crevice or a protected area in the bark, it thrusts its proboscis into the bark tissues, where it remains permanently. Larvæ have not been known to remove themselves from this first location to another after once becoming attached. Larvæ which have become detached somewhat later in life are able to crawl about feebly, but finally die without being able to attach themselves again. Although the legs are retained throughout the full lifetime, they are of no further use to the female larva except to aid in removing the cast skins when molting.

Larvæ will attach themselves on twigs as small as one-fourth inch in diameter and on trunks a foot or more in diameter, provided the bark is not too thick to be pierced with their proboscides. A few scale insects have been found infesting the smooth trunk of seedlings less than one-half inch in diameter, but rough bark is essential to a heavy infestation. The deeper the larvæ are able to go into the crevices the more satisfied they appear to be. They have been found so well secreted in crevices that it would seem there was no room left for their future growth, and much less any chance of mating, particularly after being enveloped with a white flocculent secretion.

LARVA.

FIRST INSTAR.

Immediately after attachment the larva begins enveloping itself with this white cotton until entirely hidden from view. A drop of honeydew, resembling pitch, is emitted by some larvæ, especially on vigorous trees, during the first few weeks after attachment.

Growth starts immediately after attachment and is practically constant throughout the whole instar. The larva at the end of the instar is very similar to those just hatched, except that the former are larger, somewhat broader in proportion to their length, and slightly darker in color.

At the end of the first instar, the larva molts, the skin being pushed down off the tip of the abdomen. From 40 to 44 days were required to complete the first instar in the few cases observed.

SECOND INSTAR.

There is very little development during the second stage. The female larva secretes more waxy cotton and changes in size and shape until it resembles the adult female. After a period of from one to two months the second molt occurs and the larva becomes an immature adult.

The male larva increases in size and becomes yellowish white in color. It takes on a firmer and trimmer appearance. After a slightly shorter time than that required by the female larva, the male larva detaches itself and crawls about in search of a favorable place in which to pupate. It may pick a spot under some cotton or in a curl of the outer bark. Cocoons have also been found in the cast skins of coccinellid larvæ and in the ruptured bodies of dead female scale insects.

Here the male larva proceeds to spin a cocoon, secreting cottony wax from the small ducts which occur on both the dorsum and venter of the body, turning over and over in the operation. The cotton secreted is finer than that secreted by the female larva, as would be expected because of the smaller ducts on the male.

It requires three or four days to complete the cocoon. After a day or two of inactivity, the larva molts to a prepupa, pushing the cast skin out through a slit which is in the rear end of the cocoon.

MALE PREPUPA AND PUPA.

The male from now on is without mouth parts, and during this dormant period is an inactive creature, capable only of feebly waving its front legs and wriggling its abdomen when disturbed.

The male remains in this stage from 10 to 15 days, and with this molt becomes a true pupa, greatly resembling the adult male. As in the previous stage, the pupa is inactive. Normally the same length of time is required for this stage as for the previous one. A few pupæ have been found hibernating in the colder Sierras.

ADULT.

MALE.

When the pupal skin is cast, the male's wings are extended to their full size and then folded, one over the other, upon its back. As soon as the wax filaments have grown to their full length, which requires from 30 minutes to several hours, the male backs out of the cocoon and becomes very active. It immediately begins searching for a mate. The length of life of the male is never more than one or two days and death occurs very soon after mating.

FEMALE.

The color of the female becomes darker after the second and last molt, and upon becoming heavily chitinized is a dark reddish brown. After mating the body increases considerably in size, becoming nearly globular. Inside the female's body may be found a large number of eggs in different stages of development. The body still is covered quite thoroughly with cotton and deeply hidden in the bark crevices. Upon becoming an adult a new supply of coarser threads of wax is excreted. After depositing the eggs, an act which covers a considerable period of time, the female shrivels and dies, nothing but the chitinized skin remaining. If the host plant is still alive, this vacancy is soon filled by a female of the next generation.

SEASONAL HISTORY.

(Fig. 3.)

There is but one generation per year, the limits of which are not very definite. The males appear in the fall, being most abundant in

October and November. These mate and die in a few days. At this time most of the females have cast their last skin and are about one-half grown.

The winter is passed as adult females, with no very definite period of hibernation in the lower altitudes. In the Sierra Nevadas there is a more definite period of hibernation and the generations are more even. The female larvæ become adults somewhat earlier in the fall. When the cold weather strikes them, development becomes very slow. In December females are found containing a few eggs. These develop during the winter and early spring.

Oviposition begins on the first warm days of spring and lasts throughout the summer, beginning about April 1 and terminating the latter part of September. In the fall the females, having com-

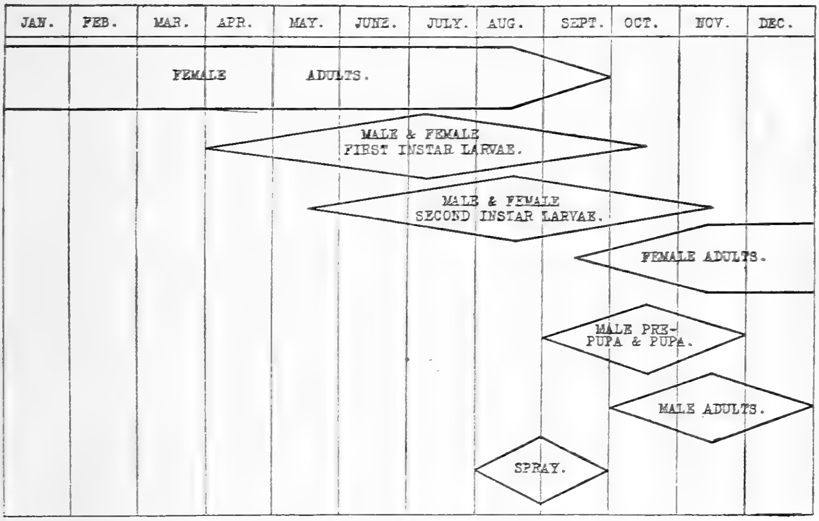


FIG. 3.—Seasonal history diagram of the cypress bark scale.

pleted oviposition, shrivel and die. By this time the young females of the next generation are quite well developed, thus assuring the presence of adult females during the whole year.

The larvæ issue from the eggs 30 or 40 minutes after deposition and soon attach themselves. Larvæ of the first instar may be found from April to the middle of October, second-instar larvæ from the middle of May to the middle of November, and adult females from about September 15 to the following September. Male prepupæ and pupæ may be found in September, October, and November, and adults in October, November, and December. A male pupa was found hibernating in the Sierra Nevadas. A few scattering first and second stage larvæ may be found during the winter in the milder climate near the coast.

PREDACIOUS AND PARASITIC ENEMIES.

There are several coccinellids which aid in the control of the cypress bark scale. None of them is aggressive enough, however, to affect its abundance very materially.

A very small ladybird, *Nipus biplagiatus* Casey (fig. 4), is the most abundant and widespread enemy of the scale. This is a sturdy little beetle, about 1.3 mm. in length, brownish black, with a lighter amber spot in the center of each elytron. It is generally present wherever the scale insect is to be found. On one side of a cypress limb in a space 3½ by 24 inches (84 square inches), there were found 46 specimens of this coccinellid and in certain parts of this area there were as many as four beetles to the square inch. There were undoubtedly still more out of sight under the bark scales. Very few of the larvæ of this beetle were seen but this may be accounted for by their extremely small size and their pale brown color.

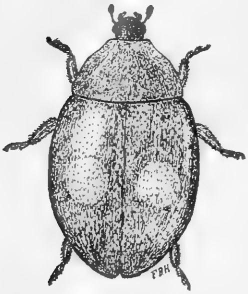


FIG. 4.—*Nipus biplagiatus*, a coccinellid enemy of the cypress bark scale. × 25.

A small black nitidulid beetle, *Cybocephalus californicus* Horn (fig. 5), is very abundant and is sometimes confused with the above coccinellid. It is, however, slightly smaller, shiny black, with more delicate legs, and of a more compact globose form. This beetle has not been seen actually feeding upon the scale insect, yet it is believed to be an aggressive predacious enemy. It is always found about the scale insect, and often with its head in the bark crevices as if feeding upon the scale insect. The larva of this beetle is small and white and not easily found.

FIG. 5.—*Cybocephalus californicus*, a nitidulid beetle always found about the cypress bark scale. × 25.

The twice-stabbed ladybird, *Chilocorus bivulnerus* Muls., is an abundant and aggressive predator upon the cypress bark scale. This beetle is often found upon cypress, feeding upon this insect pest.

The common black-spotted red ladybird, *Hippodamia convergens* Guérin, has been found a few times feeding upon the scale. As this beetle breeds in great numbers in the Sierra Nevadas, it probably feeds upon the scale on incense cedar in its native haunt.

Larvæ of the common brown lacewing, *Sympherobius angustus* Banks, are often found feeding upon the cypress bark scale and aiding materially in retarding its increase and spread.

A few specimens of a small hymenopterous parasite have been reared from caged material of this scale insect. It can not, however, be considered as of any importance, because of its great scarcity. In all the writer's observations but three scale insects have been found with punctures in them, from which parasites have escaped. Two of them were from Monterey cypress and one from incense cedar in the Sierra Nevadas. The scarcity of this scale insect in the Sierras would indicate that a parasite was quite active upon it. If such is the case, it has not as yet been noted.

CONTROL EXPERIMENTS.

A series of experiments was undertaken in order to find one or more materials capable of reducing the numbers of this very harmful pest. Only those sprays were experimented with which would be able to penetrate well into the crevices of the bark, where many of the scales were located. Oil sprays are the only ones which meet these requirements, consequently no others were tried. The oil sprays are capable of penetrating and creeping into all the tiny cracks and crevices of the bark when properly applied. The higher the gravity of oil used, the better is the penetration.

First, crude-oil emulsion was used, but, being a low-gravity oil, it was unsatisfactory. Next, distillate emulsion was used and, being of somewhat higher gravity, was more satisfactory, but still did not kill more than 40 per cent of the scale insects. Miscible oil No. 1 was next used, being of about 28° Baumé gravity. This used in a 12½ per cent solution was quite satisfactory, destroying from 75 to 90 per cent of the scale insects. A well-known washing powder was tried as an emulsifier with both the emulsion and the miscible oil, but proved of no value, so its use was discontinued.

Carbolic sheep dip was tried out, as this was reported to have very good penetrating powers. This, however, gave only about 30 per cent efficiency and was not used further. Six per cent was the highest used with this, as a higher percentage was believed to be dangerous to the tree. It also made the lungs of the experimenter quite sore.

Next, miscible oil No. 2 was experimented with, for this had the very high gravity of 33° Baumé. A 12½ per cent solution of this proved quite satisfactory, killing a high percentage of the scales and upon second application destroying virtually 100 per cent. Further experiments with this substantiated these results.

In Table II are recorded all spraying experiments performed upon the cypress bark scale. All spraying was done in the warm part of the day, generally in the afternoon, when the trees were dry. The spray was applied very heavily and thoroughly, every part sprayed being completely drenched. In experiments Nos. 19, 20, and 21 (small trees) the entire tree was sprayed; in all others only the trunk, lower limbs, and foliage were sprayed, as the trees were too large to be treated with a hand pump. The cypress foliage appears to be very resistant, for no burning occurred at any time from the application of the spray.

It was discovered that the small larvæ were much more easily killed than the adult females. All larvæ could not be killed with one spraying, however, on account of the long period of hatching. The last of the brood were not hatched by the time the first were becoming adults; consequently two sprayings were necessary, one to exterminate the early hatched larvæ, the other to exterminate those hatched later.

TABLE II.—*Record of spraying experiments performed upon the cypress bark scale.*

No.	Date.	Formula.	Number of trees.	Per cent of efficiency.	Remarks.
	1918.				
1	Feb. 25	Crude-oil emulsion, 7½ per cent	6	0	In shade.
2	Mar. 9	Distillate emulsion, 3 per cent	3	0	Rained that night and following 3 days.
3	...do	Distillate emulsion, 5 per cent	5	0	Do.
4	Mar. 28	Distillate emulsion, 6 per cent	4	25	In shade.
5	Apr. 10	Distillate emulsion, 7½ per cent	3	20	Warm, dry.
6	...do	Distillate emulsion, 7½ per cent, and washing powder, 1 pound to 20 gals.	3	20	Do.
7	Apr. 24	Distillate emulsion, 12 per cent	2	40	Do.
8	June 4	Carbolic sheep dip, 3 per cent	3	30	Hot, dry.
9	July 18	Carbolic sheep dip, 6 per cent	2	30	Do.
10	Mar. 28	Miscible oil No. 1, 6 per cent	4	25	Warm, in shade.
11	Mar. 29	Miscible oil No. 1, 6 per cent, and washing powder, 1 to 20.	3	40	Warm, dry.
12	Apr. 24	Miscible oil No. 1, 12½ per cent	2	75	Do.
13	...do	Miscible oil No. 1, 12½ per cent, and washing powder, 1 to 20.	2	40	Do.
14	Oct. 7	Miscible oil No. 1, 12½ per cent	2	90	Warm, dry; repeat on No. 12.
15	...do	Miscible oil No. 1, 8 per cent	2	75	Warm, dry; repeat on No. 11.
16	July 18	Miscible oil No. 2, 12½ per cent	2	75	Warm, dry; killed 50 per cent adults and 99 per cent larvæ.
17	Oct. 7	.....do	1	75	Warm, dry; rained 2 days ago.
18	...do	.....do	1	100	Rained 2 days ago; repeat on 1 tree No. 16.
19	Oct. 26	.....do	38	80	Hedge of young trees.
20	Oct. 28	.....do	39	80	Do.
21	...do	.....do	1	85	Repeat on tree No. 38 of Experiment No. 19.

In experiments Nos. 1 to 7, percentages are of actual oil content, not emulsion content.

RECOMMENDATIONS FOR CONTROL.

The following measures are recommended for the control of the scale insect.

Cut out all dying trees or limbs of trees beyond saving and destroy them in order to reduce all possible sources of infestation.

Purchase clean nursery stock for planting. If the stock is infested, return it to the nursery and demand clean stock to replace it.

Most fruit growers now realize that spraying is necessary for the maintenance of healthy trees and the production of clean fruit. Most people, however, still believe that a shade tree should always be able to take care of itself. One can not hope to maintain healthful, vigorous, shade and ornamental trees without proper care and occasional spraying.

Infested trees should be sprayed twice in the fall, once in August or the first part of September and again in the latter part of September. This is to kill the larvæ before they become mature. The proper dates to spray may vary slightly in different localities and with different seasons, in which case certain phenological events may be relied upon. The first spraying should be done when the fruit of the French prune (the common variety planted throughout the State) becomes blue or first begins to fall from the tree. The second spraying should be done from one to two weeks after the last prunes have been harvested. If but one application is attempted, spray in the middle of September or when the maximum number of prunes are falling from the trees, as this would be the best time to kill the greatest number of larvæ.

The only satisfactory material to be used is a 12½ per cent solution of a high gravity miscible oil (33° Baumé). The proportions are as follows:

	Part.
Miscible oil (33° Baumé)	1
Water	7

Put the requisite amount of oil in the pail or barrel to be used and add about one-fifth that amount of water. After some stirring this will become a thick creamy liquid, whereupon the remaining amount of water may be added with constant stirring. This should be continually agitated while being applied.

The ordinary barrel or bucket pump will serve very well in applying the spray to small trees. A good power apparatus, however, is necessary in order to compel the spray to reach to the top of large trees or to penetrate through the heavy foliage of thick hedges.

Thoroughness of the application can not be overemphasized. It is absolutely necessary for successful control. See that the spray comes in contact with every twig and that all the larger limbs and trunks are thoroughly drenched.

When planting trees not intended for trimmed hedges or windbreaks, leave a wide space between each individual. It is a common fault to plant all sorts of trees too closely. Cypresses planted purely for ornament should be fully 40 or 50 feet apart. Trees already planted can be thinned out to this distance. This will retard the spread of the insect and give more nourishment to each tree left. The addition of fertilizers and water about the base of infested trees will also aid in overcoming the effects of the scale insect.

In badly infested regions it is not advisable to replant cypresses. There are many other species of trees which are less prone to infestation and are just as ornamental, which should be planted. There are other trees and plants, also, which make effective trimmed hedges.

The common privet (*Ligustrum vulgare* Linn.) forms an admirable hedge. The holly-leaf cherry (*Prunus ilicifolia* Walp.), *Atriplex canescens* James, and *Pittosporum* spp. also are recommended. Pittosporum, however, is subject to attacks from scale insects which are just as difficult to control as the cypress bark scale. The Oriental and Italian cypresses form quite effective coniferous hedges, the latter being tall and slender. Certain forms of red cedar (*Juniperus virginiana* Linn.) are used as trimmed hedges in certain sections of the United States. If this proves to be immune to the scale insect, it should be a very good substitute for the Monterey cypress.

SUMMARY.

The main cause of the browning and death of so many cypress trees, hedges, and windbreaks throughout California is the cypress bark scale, *Ehrhornia cupressi.*

It was found in the course of a thorough investigation that the scale insect was not a native of the Monterey cypress, but of the incense cedar which occurs in the mountains of California, Nevada, and southern Oregon. From this host it has probably spread to the Monterey cypress by the transportation of incense-cedar seedlings or rustic timber to the regions infested.

The characteristic injury caused by this insect begins to show on one or two limbs and slowly spreads to the rest of the tree. The foliage turns first yellow, then red or brown, giving the tree a very dilapidated appearance. After a few years the whole tree dies.

The food plants of the cypress bark scale are Monterey cypress, Arizona cypress, Guadalupe cypress, and incense cedar.

The larvæ are small oval bodies, pale yellow in color, which are active for a short time after hatching. They attach themselves in crevices of the bark and are soon enveloped in a white cottony secretion. As they reach maturity they become reddish-brown in color and nearly spherical in shape.

Oviposition begins in the spring and lasts throughout the summer. The eggs hatch into larvæ in less than an hour and soon attach themselves. The females reach maturity in the fall and hibernate over the winter, starting oviposition in the spring. The males appear in the late fall or early winter to mate and die.

There are several insects which prey upon the cypress bark scale, none of which, however, is abundant enough to control the scale insect. Consequently remedial measures have to be adopted. A $12\frac{1}{2}$ per cent solution of a high-gravity miscible oil is the spray recommended. To obtain complete control it is necessary to spray twice in the early fall, once in August and once in the latter part of September.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 839

Contribution from the Bureau of Chemistry
CARL L. ALSBERG, Chief

Washington, D. C. April 23, 1920

MICROSCOPICAL EXAMINATION OF FLOUR.

By George L. Keenan, *Microanalyst*, and Mary A. Lyons, *Microanalyst*, *Microchemical Laboratory*.

CONTENTS.

REVIEW OF LITERATURE.

A review of the literature has shown very few methods for the microscopical examination of flours. In the great majority of the methods found, suggestions are offered for the separation of the wheat tissues from the starch material and the subsequent examination of the offal under the microscope. The results obtained from such microscopical examination, however, are only roughly indicative of the offal that may be present.

The work of Delaye (5)[1] was concerned largely with the detection of foreign spores in flour and also with the presence of ergot. Girard (7) suggested the separation of the gluten from the starch and impurities by forming the flour into a cake and washing it with running water. The starch and impurities were separated with a fine sieve, and the offal particles examined under the microscope. Kraemer (11) has offered a quantitative method for the examination of commercial flours by means of the microscope, this quantitative method to be preceded by a general qualitative examination. A small portion of the flour was weighed out, a few drops of a reagent added, and the number of typical starch grains or characteristic tissues enumerated in examining five different portions of the microscopical mount. Standard samples were employed for purposes of com-

[1] The numbers in parenthesis refer to the bibliography on page 32.

parison. As a rule, not less than 12 microscopical mounts were made of the standard and of the sample under examination.

Kohn (10) weighed out one-half gram of the flour, and added 10 cubic centimeters of ether, shaking the mixture, to isolate the hairs and bran tissues which were subsequently identified under the microscope.

Dedrick (4) placed the flour in question upon a glass, and examined it for offal particles, either with the naked eye or by means of a powerful magnifier. Particles of bran, germ, or other impurities or substances differing from flour were enumerated, five and six trials being made and an average struck. In this way he attempted to differentiate between the so-called patent, straight, clear, break, and low-grade flours.

Collin (3) considered the microscopical examination of flour quite extensively, although he did not take up the question from the standpoint of determining the relative amount of offal material present. The histology of the wheat grain is fully discussed and illustrated with a number of figures.

Von Liebermann and Andriska (22) suggested a method for estimating the quality of wheat flour which might possibly be correlated with a microscopical examination. The quality of the flour with respect to the quantity of bran substance present was ascertained by shaking the flour with chloroform, and observing the color of the portion which floated on the surface. The test might be rendered quantitative in the following manner: One gram of the flour was shaken in a tube with 10 cubic centimeters of chloroform, and the mixture allowed to stand for one hour. The depth of color of the layer which then formed on the surface of the chloroform was compared with the colors of the layers produced when mixtures of finest white flours and variable portions of bran were subjected to similar treatment. These mixtures might contain quantities of washed bran ranging from 0 to 2 per cent. The colors of the layers were to be observed from above.

In connection with the work done by Moore and Wilson (15), Patterson has made a microscopical examination of the flour streams from the different machines of the mill, these streams being blended to form various finished flours. Finished flours were also examined. His method consisted in weighing out 3 milligrams (0.003 gram) of flour, dividing this into five portions on as many microscopic slides, wetting with water, covering with cover slips, and then counting under the microscope the number of hairs and epicarp and seedcoat particles in the five slides. His results tended to show how these particles increased in number in streams from the lower-grade machines and were practically absent from those from the "top" of the mill.

PURPOSE OF INVESTIGATION.

From the review of the literature, it is apparent that heretofore the purpose of the microscopical examination of flour has usually been to determine the presence of adulterants, such as other flours, or even starches, spores, etc. The paper in which Patterson indicated the possibilities of an estimation of the offal content of a flour microscopically (15) suggested the work here reported.

MICROSCOPICAL METHOD.

For convenience, the microscopical method employed in this investigation will be described under the following headings: (1) Apparatus, (2) technique, and (3) counting bran particles and hairs.

APPARATUS.

1. Microscopic slide with a ruled area about 22 millimeters square. The lines, which it is convenient to have about $\frac{1}{2}$ millimeter apart, are ruled across the short diameter of the slide.
2. Cover glasses 22 millimeters square.
3. Compound microscope, with compensating ocular 12× and 16 mm. apochromatic objective.
4. Scalpel, preparation needles, camel's-hair brush, spatula, alcohol lamp, mechanical stage.
5. Assay balance.
6. Chloral hydrate solution about 1:1; preferably not any more concentrated.

TECHNIQUE.

Before undertaking the examination of a flour microscopically, the sample should be thoroughly mixed, and a composite sample withdrawn from various parts of the material. A 5-milligram portion of flour is carefully weighed out upon accurate balances, and the weighed portion transferred to the center of the ruled area on the microscopic slide. The scalpel is employed in removing flour from the weighing pan to the slide, the small amount which can not be thus removed being easily brushed onto the slide with the camel's-hair brush. The flour being transferred to the slide, about 3 or 4 drops of chloral hydrate solution are mixed with the flour by means of the preparation needle. Add only enough chloral hydrate solution to fill the space beneath the cover glass. The proper amount is usually about 4 drops when a pipette with a 1-millimeter bore is employed. A pipette of larger bore releases too much solution at a time and is less convenient to control. It is important that the material be evenly distributed in the solution; otherwise flocculation of the flour will occur, rendering counting more difficult and less accurate. The square cover glass is next applied, and the slide heated over the alcohol flame until the starch grains are dissolved, or the preparation "cleared," as is commonly stated. Vigorous heating of the slide is to be avoided in order to prevent burning of the material before the preparation has been sufficiently cleared. After gentle heating, the slide is quickly transferred to the stage of the microscope, where it is allowed to remain a short time before counting is begun. The cold stage causes the larger part of the air bubbles that may be present in the preparation to disappear, the very few that remain not hindering in the enumeration of the bran particles and hairs.

Careful adherence to the details of this technique is necessary to insure a suitable slide for counting. If a slide is improperly prepared, the resulting count probably will not be representative of the flour under consideration.

COUNTING BRAN PARTICLES AND HAIRS.

A thorough acquaintance with the histology of the wheat grain is essential before attempting an examination of flours. Any standard work on microscopy or plant anatomy of the common food products contains adequate descriptions of the tissues of the wheat berry in various sections. The following brief description of the anatomy of the wheat berry [1] is given for the purpose of indicating the tissues which are depended upon for judging a flour with respect to its offal content.

The wheat grain is, botanically, the fruit of various subspecies and varieties of the genus Triticum. This grain or fruit consists of a series of tissue systems, the outermost of which is the pericarp which is composed of three layers, the epicarp, mesocarp, and endocarp. The pericarp is essentially the fruit coat or matured ovary wall. Within the pericarp is the testa (or spermoderm), rather yellowish-brown in color, and easily distinguished in either cross or surface sections under the microscope. Within the testa is a layer of rectangular cells (in transverse section) known as the aleurone layer, containing protein material but no starch. This is essentially the outer layer of the endosperm or albumen of the seed. The remainder of the grain within the aleurone layer consists of very thin-walled parenchymatous cells packed full of starch grains. The small embryo, or germ, is located at the end opposite the bearded apex. A crease or groove passes longitudinally from the base of the grain to the apex.

The essential purpose of milling is to produce the finely ground endosperm or starchy portion of the wheat grain as free as possible from bran particles, hairs, and germ tissues. These bran particles, hairs, and germ tissues are known as offal in milling terminology. The wheat offal, therefore, consists primarily of all the tissue elements of

[1] A. L. Winton. The Microscopy of Vegetable Foods, 2d ed., pp. 65–73. 1916.

the grain from, and including, the aleurone layer outward, and also the germ tissues. Botanically, the bran consists of the pericarp, or fruit coat, and the aleurone layer.

In order to discover any relation that might exist between the bran particles and hairs and the various so-called grades of flour, the microscopical method already partially described (page 3) was employed to determine the number of bran particles and hairs ordinarily found, in varying amounts, in different classes of flours. This enumeration consisted in methodically examining and recording all of the bran particles and hairs contained in any given slide. It is well to form the habit of always starting at the same point in the mount, as, for example, the lower right-hand corner of the slide. The slide is slowly moved by means of the mechanical stage, and all of the bran particles and hairs detected outside the edge of the cover slip counted. Each particle of spermoderm (with accompanying aleurone layer, if present), epicarp, cross-cell and intermediate-cell tissues, and hairs are given a value of one, no matter how small the particle or hair fragment may be, surface as well as transverse sections being included. After the region outside the cover slip is carefully scrutinized, the slide is moved over the width of the space between the ruled lines, and another strip of the mount examined and the offal[1] counted. A bran particle with hairs attached is counted as so many hairs instead of being recorded, for the sake of convention, with the bran particle count. Germ tissues were not enumerated. This procedure, as described, is methodically followed until the entire slide has been examined.

SOURCES OF VARIATION IN METHOD.

In order to study the reliability of the method aside from its practical application to the examination of flour, a large number of tests were made having for their principal purpose the determination of the probable sources of variation and their extent. In considering this question it was recognized that there might be a variation due to one or all of the following factors: (1) Personal equation, including one analyst's variation in counting the same slide on different days and the variation between two analysts counting the same slide on the same day; (2) daily variation due to the condition of light, etc.; (3) slide variation due to limits of accurate weighing of the test portion of flour; and (4) the variation in homogeneity of the bulk sample.

[1] For the purpose of this investigation bran particles and hairs were considered as constituting the offal.

PERSONAL EQUATION VARIATION.

COUNTING THE SAME SLIDES ON DIFFERENT DAYS BY ONE ANALYST.

Table 1 gives actual data obtained from counts made by each of two analysts working upon three slides which were prepared from the same bulk sample and upon which they made two counts on each of three successive days.

TABLE 1.—*Results of counts of same slides by two analysts on different days.*

Date.	Slide.	Analyst.	Count No.	Bran particles.	Hairs.	Total.
1918.						
Jan. 7	A	Keenan	1	87	59	146
Do.	A	do	2	92	64	156
Do.	B	do	1	60	60	120
Do.	B	do	2	60	58	118
Do.	C	do	1	87	62	149
Do.	C	do	2	81	74	155
Do.	A	Lyons	1	103	58	161
Do.	A	do	2	114	52	166
Do.	B	do	1	86	64	150
Do.	B	do	2	80	58	138
Do.	C	do	1	90	62	152
Do.	C	do	2	87	57	144
Jan. 8	A	Keenan	1	76	66	142
Do.	A	do	2	82	69	151
Do.	B	do	1	60	55	115
Do.	B	do	2	49	48	97
Do.	C	do	1	62	66	128
Do.	C	do	2	64	68	132
Do.	A	Lyons	1	100	54	154
Do.	A	do	2	96	56	152
Do.	B	do	1	85	52	137
Do.	B	do	2	77	55	132
Do.	C	do	1	89	65	154
Do.	C	do	2	83	59	142
Jan. 9	A	Keenan	1	80	65	145
Do.	A	do	2	83	66	149
Do.	B	do	1	49	61	110
Do.	B	do	2	53	57	110
Do.	C	do	1	60	66	126
Do.	C	do	2	77	71	148
Do.	A	Lyons	1	104	54	158
Do.	A	do	2	106	55	161
Do.	B	do	1	78	55	133
Do.	B	do	2	77	55	132
Do.	C	do	1	86	65	151
Do.	C	do	2	86	62	148

For the purpose of emphasizing certain salient points, the results recorded in Table 1 have been rearranged in Table 2, in considering which it is necessary to regard the different portions carefully. Keenan's greatest variation in two counts of bran particles on a given slide on any one day was 17 points (slide C, Jan. 9, 1918), while Lyons' greatest variation was 11 points (slide A, Jan. 7, 1918). In the matter of counting hairs the greatest variation in the counts obtained on a given slide on any one day by Keenan was 12 points (slide C, Jan. 7, 1918), while Lyons' greatest similar variation was 6 (in several instances). In these cases it appears therefore that the personal variation due to the error of counting probably would not exceed 17 points in the case of particles or 12 points in the case of hairs.

TABLE 2.—*Variation in counting of each analyst.*

Slide.	Count No.	Bran particles.			Hairs.		
		Jan. 7, 1918.	Jan. 8, 1918.	Jan. 9, 1918.	Jan. 7, 1918.	Jan. 8, 1918.	Jan. 9, 1918.
	Keenan.						
A	1	87	76	80	59	66	65
A	2	92	82	83	64	69	66
B	1	60	60	49	60	55	61
B	2	60	49	53	58	48	57
C	1	87	62	60	62	66	66
C	2	81	64	77	74	68	71
	Lyons.						
A	1	103	100	104	58	54	54
A	2	114	96	106	52	56	55
B	1	86	85	78	64	52	55
B	2	80	77	77	58	55	55
C	1	90	89	86	62	65	65
C	2	87	83	86	59	62	63

COUNTING THE SAME SLIDE ON THE SAME DAY BY TWO ANALYSTS.

The variation between the counts made by two analysts on the same slide on the same day is demonstrated by comparing the daily averages [1] obtained by each of the two analysts. These data are compiled in Table 3.

TABLE 3.—*Variation in counting of two analysts on same day.*

Date.	Analyst.	Bran particles.			Hairs.		
		Slide A.	Slide B.	Slide C.	Slide A.	Slide B.	Slide C.
1918.							
Jan. 7	Keenan	89	60	84	61	59	68
	Lyons	108	83	88	55	61	59
	Variation	19	23	4	6	2	9
Jan. 8	Keenan	79	54	63	67	51	67
	Lyons	98	81	86	55	53	62
	Variation	19	27	23	12	2	5
Jan. 9	Keenan	81	51	68	65	59	68
	Lyons	105	77	86	54	55	63
	Variation	24	26	18	11	4	5

The table shows an average variation in the count of bran particles of 20, with a range of from 4 to 27. The average variation in the count of hairs was 18, with a range of from 2 to 12. It is evident that the variation between analysts in making the count of bran particles is greater than in making the count on hairs.

DAILY VARIATION DUE TO CONDITION OF LIGHT, ETC.

To determine what influence, if any, physical conditions, such as degree of light, have upon the count, it is necessary to first eliminate, as far as possible, the personal variations already considered. This may be accomplished by taking the average of two counts on three

[1] By "daily average" is meant the average of two counts made by the same analyst on the same slide on a given day.

slides for the same day and averaging the three results to determine the analyst's daily variation. This is calculated for each analyst. The ultimate daily variation is the average of the daily variation of the two analysts computed for each day. The daily variation for each analyst is shown in Table 4.

TABLE 4.—*Daily variation for each analyst.*

Slide.	Variation.	Bran particles.			Hairs.		
		Jan. 7, 1918.	Jan. 8, 1918.	Jan. 9, 1918.	Jan. 7, 1918.	Jan. 8, 1918.	Jan. 9, 1918.
	Keenan.						
A		89	79	81	61	67	65
B		60	54	51	59	51	59
C		84	63	68	68	67	68
	Analyst's daily	77	65	66	62	61	64
	Lyons.						
A		108	98	105	55	55	54
B		83	81	77	61	53	55
C		88	86	86	59	62	63
	Analyst's daily	93	88	86	58	56	57
	Ultimate daily	85	76	76	60	63	60

The results in Table 4 seem to indicate that on January 7, 1918, there was a tendency to count higher on bran particles than on the other days. It is believed, however, that this was in whole or in part due to the clearing action of the glycerin employed to preserve the slides for counting on subsequent days, which tended to make the identification of the bran particles more difficult after the first day.

SLIDE VARIATION DUE TO LIMITS OF ACCURATE WEIGHING OF THE TEST PORTION OF FLOUR.

In order to determine the absolute variation between the slides, it is evident that an average must be obtained from which the personal variations and the daily variations have been eliminated as far as possible. This is accomplished by computing for each slide the average of all counts made on bran particles, and also making a similar computation for the hair count (Table 5).

TABLE 5.—*Counts of bran particles and hairs on slides.*

Bran particles.			Hairs.		
Slide A.	Slide B.	Slide C.	Slide A.	Slide B.	Slide C.
89	60	84	61	59	68
79	54	63	67	51	67
81	51	68	65	59	68
108	83	88	55	61	59
98	81	86	55	53	62
105	77	86	54	55	63
[1] 93	[1] 67	[1] 79	[1] 59	[1] 56	[1] 64

[1] Average slide count.

The variation in the counts on these slides naturally raises the question of the limits of accuracy in weighing out the test portion of flour. Since the amount of flour used on a slide is 5 milligrams, it is desirable to determine how great is the error due to weighing the test portion of flour. The balance employed in this investigation was a fine assay balance. In weighing the sample the vibration method was used, and the quantity of flour was so adjusted as to produce a deviation of approximately not more than one-fourth of a space on each side of the zero point of the scale. This is equivalent to not more than 1/40 milligram, or one-half of 1 per cent, on the basis of the portion of flour used (5 milligrams). Hence any error in weighing can not be accepted as an explanation of the difference in slide counts.

VARIATION IN HOMOGENEITY OF BULK SAMPLE.

The question has been raised as to whether or not a portion of the slide variation might not be accredited to lack of uniformity of the bulk sample, due to the fact that any grade of flour is usually the component result of several constituent streams which vary more or less among themselves. The fact that in general practice the flour stocks are subjected to a certain degree of purification, however, leaves this factor little chance to figure to any great extent. This point was tested by passing a certain sample of flour which had an average count of 32 bran particles and 64 hairs through a 30-mesh sieve and making up and counting 12 slides. The bulk sample was then passed through the sieve once more (making two times for the sample), and another series of slides made and counted. Finally, the sample was put through the sieve twice more (making four times for the sample), and a third series of 12 slides made and counted. The results of these tests are given in Table 6, the counts in which are the average of the results obtained by two persons.

TABLE 6.—*Effect of variation in homogeneity of sample on count.*

Sample passed through 30-mesh sieve—					
Once.		Twice.		Four times.	
Bran particles.	Hairs.	Bran particles.	Hairs.	Bran particles.	Hairs.
31	73	26	67	21	76
48	73	37	70	22	53
36	58	25	58	30	56
33	53	22	54	32	81
41	64	27	61	23	79
36	64	32	57	29	66
35	74	32	83	36	60
35	75	27	64	34	56
37	57	34	61	39	70
35	76	26	72	38	52
30	66	39	67	33	65
34	60	30	67	37	48
[1] 35	[1] 66	[1] 29	[1] 65	[1] 31	[1] 63
[2] 18	[2] 23	[2] 17	[2] 29	[2] 18	[2] 31

[1] Average. [2] Variation

Apparently, sifting or thorough mixing of the flour a number of times has little appreciable effect upon the offal count obtained.

NUMBER OF SLIDES COUNTED.

In practice, two slides, or at most three, from the sample of flour have been used as the basis for judgment as to the character of the product as far as the offal material was concerned, and the question might very properly be asked if that number is sufficient. In order to test out this point, 12 slides were prepared from the same bulk sample of flour. Two counts on each slide were made of the bran particles and hairs by each of two analysts. The results obtained are recorded in Table 7.

TABLE 7.—*Counts on 12 slides.*

Slide designation.	Analyst.	Count No.	Bran particles.	Hairs.	Slide designation.	Analyst.	Count No.	Bran particles.	Hairs.
A	Keenan	1	21	76	G	Keenan	1	38	64
A	do	2	22	75	G	do	2	32	57
A	Lyons	1	20	78	G	Lyons	1	35	61
A	do	2	22	77	G	do	2	40	61
B	Keenan	1	24	54	H	Keenan	1	37	61
B	do	2	23	53	H	do	2	24	47
B	Lyons	1	19	52	H	Lyons	1	38	56
B	do	2	23	56	H	do	2	40	61
C	Keenan	1	23	55	I	Keenan	1	26	74
C	do	2	31	60	I	do	2	44	67
C	Lyons	1	34	59	I	Lyons	1	44	67
C	do	2	33	53	I	do	2	42	72
D	Keenan	1	33	77	J	Keenan	1	39	50
D	do	2	30	81	J	do	2	38	55
D	Lyons	1	31	84	J	Lyons	1	34	48
D	do	2	35	82	J	do	2	41	56
E	Keenan	1	24	79	K	Keenan	1	32	63
E	do	2	22	79	K	do	2	30	60
E	Lyons	1	23	82	K	Lyons	1	33	68
E	do	2	26	78	K	do	2	37	71
F	Keenan	1	31	64	L	Keenan	1	32	47
F	do	2	29	65	L	do	2	36	49
F	Lyons	1	29	70	L	Lyons	1	42	47
F	do	2	30	66	L	do	2	39	51

From the data in Table 7 it is possible to average Keenan's first count on slide A with each count made by him on each of the other slides. By averaging the slides by two, 20 is found to be the lowest average and 43 the highest average for bran particles, considering Keenan's results only. If the average of counts for three slides instead of two is to be taken as the basis for final judgment of the product, it is apparent that 22 is the average of the three lowest results and 40 the average of the three highest (Keenan's results on bran particles). Taking the average of the counts on each of four slides gives an average minimum count of 22 and an average maximum count of 39. Table 8, based on data obtained from Table 7, has been prepared to show the results of such methods of grouping.

TABLE 8.—*Effect of method of computing average on count.*

Method of averaging.	Bran particles.				Hairs.			
	Keenan.		Lyons.		Keenan.		Lyons.	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
By twos	20	43	19	43	48	80	49	83
By threes	22	40	20	42	47	79	48	81
By fours	22	39	21	41	49	79	49	81
By fives	23	39	21	41	51	77	50	80

EXAMINATION OF MILL STOCKS.[1]

Before undertaking a discussion of the work done on finished commercial flours, it seemed advisable to consider the degree of purity of the various mill stocks entering into the composition of the end-product. The data compiled in Table 9 demonstrate the quality of the stocks made on the break rolls, the purpose of which is to crush the wheat kernel to release the enclosed endosperm that is later reduced to fineness on other rolls and finally purified of offal débris. The general practice in milling is to make as little break flour as possible. When break flour is made to any extent, it invariably contains a notable amount of offal, consisting of bran particles, as well as numerous hairs from the beard. The results recorded in Table 9 were obtained on samples of material procured from the first, second, third, and fourth break rolls, respectively, and from different mills. It was stated that they had been bolted through silks of various numbers of meshes per lineal inch, the following silks being employed:

Silk number.	Meshes per inch.
10xx	109
11xx	116
12xx	125
12x	125
12xxx	125
13xx	129
14xxx	139

[1] The designations for the various stocks and grades of flour examined, as well as the statements concerning the kind of wheat from which the flour was milled, were taken from the millers supplying the samples and were not verified in the Bureau of Chemistry.

TABLE 9.—*Results of examination of products from break machines.*

Sample No.	Type of wheat.	Bolting cloth.	Bran particles.	Hairs.	Total.
		FIRST BREAK MATERIAL.			
11079-K-A	Hard	(?)	196	165	361
17146-L-B	do	11xx, 13xx	186	83	269
17125-L-C	Hard and soft	(?)	117	43	160
17128-L-A	do	(?)	334	162	496
17159-L-A	do	(?)	76	61	137
17173-L-A	do	(?)	46	64	110
17165-L-O	Soft	10xx	113	38	151
17167-L-A	do	12xxx, 14xxx	182	58	240
		SECOND BREAK MATERIAL.			
17143-L-B	Hard	10x, 11x	324	42	366
17146-L-A	do	12xx, 13xx	166	65	231
17190-L-B	do	12xx, 13xx	216	162	378
17125-L-D	Hard and soft	(?)	105	23	128
17128-L-C	do	(?)	150	83	233
17159-L-B	do	(?)	47	44	91
17173-L-B	do	(?)	32	54	86
17133-L-F	Soft	(?)	142	58	200
17165-L-P	do	10xx	75	38	113
17167-L-B	do	12xxx, 14xxx	138	31	169
		THIRD BREAK MATERIAL.			
11079-K-D	Hard	(?)	120	121	241
17143-L-C	do	10x, 11x	628	107	735
17146-L-D	do	12xx, 13xx	367	144	511
17125-L-E	Hard and soft	(?)	159	26	185
17128-L-D	do	(?)	118	53	171
17159-L-C	do	(?)	68	60	128
17173-L-C	do	(?)	37	56	93
17133-L-G	Soft	(?)	375	73	448
17165-L-Q	do	10xx	131	53	184
17167-L-C	do	12xxx, 14xxx	135	46	181
		FOURTH BREAK MATERIAL.			
17143-L-D	Hard	11x, 12x	810	213	1,023
17146-L-C	do	12xx, 13xx	322	116	438
17125-L-F	Hard and soft	(?)	262	57	319
17128-L-E	do	(?)	118	50	168
17173-L-D	do	(?)	132	147	279
17165-L-R	Soft	10xx	228	106	334
17167-L-D	do	14xxx	285	66	351

For the purpose of comparison, the data from Table 9 have been summarized in Table 10.

TABLE 10.—*Summary of results of examination of products from break machines.*

Machine stock.	Average.	
	Bran particles.	Hairs.
First break	156	84
Second break	139	60
Third break	213	73
Fourth break	308	122

The offal content of the break roll products is high, as would be expected. A microscopical examination is hardly necessary to establish this fact. The fluffy and dirty appearance of such products, even from casual examination, is sufficient to show that they are of low quality, judging from the offal material present.

Tests similar to those made on break roll products were made on middlings stock. Middlings are usually recognized as being the medium granular particles of the endosperm resulting from the cracking of the wheat kernel on the break rolls. After proper purification or removal of the branny material, the middlings are milled, on the reduction rolls, to the fineness of flour. The results of experimental work done on middlings stocks are recorded in Table 11.

TABLE 11.—*Results of examination of middlings stocks.*

Sample No.	Type of wheat.	Bolting cloth.	Bran particles.	Hairs.	Total.
		FIRST MIDDLINGS STOCK.			
15196-K-E	Hard	10xx, 11xx, 12xx	22	18	40
17144-L-I	....do	10x	14	4	18
17190-L-I	....do	10xx	36	16	52
17125-L-L	Hard and soft	(?)	23	2	25
17159-L-F	....do	(?)	18	22	40
17132-L-J	Soft	(?)	19	3	22
17133-L-L	....do	(?)	59	12	71
17165-L-B	....do	10xx	21	8	29
17185-L-C	....do	10xx	5	2	7
		SECOND MIDDLINGS STOCK.			
15196-K-C	Hard	12xx, 13xx, 14xx	5	3	8
17144-L-J	....do	10x	7	3	10
17146-L-G	....do	11xx, 12xx	29	2	31
17190-L-I	....do	11xx	100	50	150
17125-L-N	Hard and soft	(?)	11	1	12
17159-L-G	....do	(?)	7	5	12
17132-L-K	Soft	(?)	25	1	26
17133-L-O	....do	(?)	59	6	65
17165-L-C	....do	10xx	48	27	75
17185-L-D	....do	10xx	8	4	12
		THIRD MIDDLINGS STOCK.			
17144-L-K	Hard	10x, 11x	8	1	9
17146-L-I	....do	11x, 12xx	27	6	33
17190-L-J	....do	10xx, 11xx	14	5	19
17125-L-P	Hard and soft	(?)	6	3	9
17128-L-K	....do	(?)	69	26	95
17159-L-H	....do	(?)	19	22	41
17173-L-O	....do	(?)	18	24	42
17132-L-L	Soft	(?)	9	0	9
17133-L-Q	....do	(?)	34	5	39
17165-L-D	....do	10xx	36	7	33
17167-L-J	....do	14xxx	21	5	26
17185-L-F	....do	10xx	9	4	13
		FOURTH MIDDLINGS STOCK.			
15196-K-J	Hard	11xx, 12xx, 14xx	10	6	16
17190-L-K	....do	11xx, 12xx	76	25	101
17125-L-T	Hard and soft	(?)	7	1	8
17128-L-O	....do	(?)	38	23	61
17159-L-I	....do	(?)	8	10	18
17171-L-L	....do	11xxx, 12xx	82	9	91
17132-L-M	Soft	(?)	26	1	27
17133-L-S	....do	(?)	26	5	31
17165-L-F	....do	12xx	29	2	31
17167-L-M	....do	(?)	115	24	139
17167-L-K	....do	(?)	40	6	46
		FIFTH MIDDLINGS STOCK.			
15196-K-K	Hard	11xx, 12xx, 14xx	18	13	31
17144-L-M	....do	10x, 11x	9	1	10
17146-L-H	....do	11xx, 12xx	21	5	26
17190-L-L	....do	11xx, 12xx	74	22	96
17128-L-P	Hard and soft	(?)	74	36	110
17159-L-J	....do	(?)	10	9	19
17171-L-M	....do	12xx	65	19	84
17173-L-P	....do	(?)	57	57	114
17133-L-U	Soft	(?)	80	18	98
17165-L-H	....do	12xx	55	12	67
17167-L-O	....do	(?)	43	10	53

TABLE 11.—*Results of examination of middlings stocks*—Continued.

Sample No.	Type of wheat.	Bolting cloth.	Bran particles.	Hairs.	Total.
		SIXTH MIDDLINGS STOCK.			
15196-K-G	Hard	11xx, 12xx, 13xx, 14xx	26	30	56
17144-L-N	do	11x, 12x, 13xx	24	1	25
17190-L-M	do	11xx, 12xx	139	33	172
17125-L-BB	Hard and soft	(?)	87	15	102
17128-L-Q	do	(?)	70	37	107
17173-L-Q	do	(?)	41	66	107
17173-L-R	do	(?)	22	35	57
17133-L-W	Soft	(?)	140	18	158
17165-L-I	do	12xx	60	18	78
		SEVENTH MIDDLINGS STOCK.			
15196-K-F	Hard	12xx, 13xx, 14xx	16	9	25
17144-L-O	do	12x, 13x	36	4	40
17190-L-N	do	13xx, 14xx	119	43	162
17128-L-R	Hard and soft	(?)	63	26	89
17159-L-M	do	(?)	104	78	182
17133-L-X	Soft	(?)	194	16	210
17165-L-J	do	12xx, 13xx	143	23	166
17167-L-L	do	(?)	45	13	58
		EIGHTH MIDDLINGS STOCK.			
17190-L-O	Hard	13xx, 14xx	137	23	160
17173-L-S	Hard and soft	(?)	51	52	103
17165-L-K	Soft	13xx, 14xx	264	38	302
		NINTH MIDDLINGS STOCK.			
17167-L-S	Soft	(?)	92	25	117

The average results obtained on the middlings stocks examined have been summarized in Table 12.

TABLE 12.—*Summary of results of examination of middlings stocks.*

Stock.	Average.		Total.
	Bran particles.	Hairs.	
First middlings	24	9	33
Second middlings	29	10	39
Third middlings	21	9	30
Fourth middlings	41	10	51
Fifth middlings	46	18	64
Sixth middlings	65	26	91
Seventh middlings	90	26	116
Eighth middlings	150	37	187
Ninth middlings	92	25	117

The results in Table 12 clearly demonstrate that the middlings stocks are much cleaner than stocks obtained from the break rolls. The first five middlings stocks average low in the total offal count, while the stocks from the sixth to ninth middlings, inclusive, average appreciably higher. In other words, the more thorough the purification process, the lower will be the offal count.

For the purpose of showing the offal count on the stocks which pass into some so-called patent flours, three different sets of mill streams were examined, these streams being designated as entering into the composition of certain finished flours. The mill streams composing such flours were milled from hard, blended, and soft wheats, respectively. The results of these examinations are shown in Tables 13, 14, and 15.

TABLE 13.—*Results of examination of mill streams composing a patent flour (sample No. 17144–L–FF) milled from hard wheat.*

Stock.	Bran particles.	Hairs.	Total.
First middlings	14	4	18
Second middlings	7	3	10
Third middlings	8	1	9
Fourth middlings	19	2	21
Fifth middlings	9	1	10
Sixth middlings	24	1	25
Seventh middlings	36	4	40
Middlings	36	5	41
Do	30	5	35
First sizings	59	8	67
Second sizings	37	2	39
Sizings	151	20	171
Finished flour (70 per cent patent)[1]	13	2	15

[1] This finished flour is composed of the stocks described above it.

TABLE 14.—*Results of examination of mill streams composing a patent flour (sample No. 17159–L–V) milled from blended wheat.*

Stock.	Bran particles.	Hairs.	Total.
First break	76	61	137
Second break	47	44	91
Third break	68	60	128
Break chops	41	54	95
Do	56	84	140
First middlings	18	22	40
Second middlings	7	5	12
Third middlings	19	22	41
Fourth middlings	8	10	18
Fifth middlings (head)	10	9	19
Fifth middlings (tail)	19	14	33
Coarse tailings	19	13	32
Coarse sizings	6	8	14
Finished flour (70 per cent patent)[1]	20	15	35

[1] This finished flour is composed of the stocks described above it.

TABLE 15.—*Results of examination of mill streams composing a patent flour (sample No. 17132–L–U) milled from soft wheat.*

Stock.	Bran particles.	Hairs.	Total.
First middlings	19	3	22
Second middlings	25	1	26
Third middlings	9	0	9
Fourth middlings	26	1	27
Fine sizings	10	1	11
Medium sizings	21	2	23
Coarse sizings	14	2	16
Finished flour (60 per cent patent)[1]	19	1	20

[1] This finished flour is composed of the stocks described above it.

It is interesting to observe the variety of streams drawn upon for the composition of different so-called patents, as well as the variation in the offal count of the stocks employed in the milling of such finished flours. If space permitted, additional information could be submitted to illustrate how variable the different mill stocks are as far as offal content is concerned. In many instances where lower-grade stocks have been employed in making a flour, however, the finished product has usually been purified sufficiently to cause the resultant offal count to be appreciably low. And in many cases the contrary is true.

EXAMINATION OF COMMERCIAL GRADES OF FLOUR.

The assembled flours employed in this part of the investigation were collected by B. C. Winslow, food and drug inspector, Bureau of Chemistry, United States Department of Agriculture. As these flours were milled under a variety of conditions, they necessarily reflect such conditions in the finished product. The inspector gave the following statement as to the designations applied to these flours: "As a general thing, these names were used in harmony with the usage of the mill where they were taken. The method of assembling, with the streams, percentages, etc., were given when feasible, and as correctly as possible from the information available. The general terms 'patent,' 'clear,' and 'straight' were used to classify in a general way the assembled grades of flour, and vary with each mill."

With this information in mind, an attempt was made to apply the microscopical method already described to an examination of these products for the purpose of developing a system for the classification of flours based on the offal content. A detailed discussion of the actual data obtained from these tests, with a general summary on the various so-called grades, follows.

PATENT FLOURS.

PATENT FLOURS MILLED FROM HARD WHEATS.

Thirty-six patent flours said to have been milled from hard wheats were examined microscopically, and their bran particle and hair count determined. The commercial grade designations ranged from 40 to 94 per cent. In some instances the flour had been bleached; in others it was bleached only lightly or not at all. Table 16 gives the results of this examination.

TABLE 16.—*Results of examination of patent flours milled from hard wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent patent."				
15163-K-R	(?)	Yes	16	8	24
15178-K-U	(?)	(?)	29	13	42
17151-L-MM	40	No	19	13	32
17151-L-NN	52	No	72	45	117
17150-L-T	58½	No	27	9	36
15152-K-A	60	Yes	15	5	20
15134-K-EE	65	No	24	20	44
11078-K-LL	68	No	23	20	43
11078-K-MM	68	Yes	22	15	37
11070-K-FF	70	(?)	22	21	43
15112-K	70	No	16	12	28
15113-K	70	Lightly	17	11	28
17154-L-AA	71	No	20	10	30
15174-K-LL	72	(?)	17	4	21
15187-K-X	72	No	27	14	41
15170-K-CC	74	No	29	26	55
17144-L-FF	74	No	13	2	15
17190-L-CC	75	Yes	66	33	99
17143-L-CC	75	No	33	2	35
15193-K-EE	75	No	33	36	69
15193-K-DD	75	Yes	30	39	69
11028-K-B	75	(?)	19	13	32
17157-L-A	77	Yes	25	24	49
17183-L-A	78	No	35	28	63
17184-L-Q	79	Yes	25	31	56
11064-K-A	80	No	54	28	82
17175-L-MM	80	No	44	9	53
15181-K-S	80	No	17	19	36
17147-L-BB	83	Yes	34	16	50
17148-L-MM	83	Yes	34	10	44
17156-L-FF	83	Yes	36	30	66
17155-L-JJ	84	No	33	12	45
55135-K-CC	85	No	32	23	55
17145-L-B	85	No	36	15	51
17111-L-S	88	No	33	9	42
17180-L-JJ	94	Yes	62	34	96

On these hard-wheat patents the bran particle count ranged from 15 to 72, with an average of 30. The hair count ranged from 2 to 45, with an average of 18. The total offal count ranged from 15 to 117, with an average of 45.

PATENT FLOURS MILLED FROM SOFT WHEATS.

The patent flours milled from soft wheats are more starchy than those milled from hard wheats. This starchy character is manifest even when the sample of flour is poured out upon a piece of paper. The soft-wheat flour will not "flow" like a flour made from hard wheat, but is more "powdery" and starchlike rather than granular, as in the case of hard-wheat flours. Thirteen patent flours stated to have been milled from soft wheats were examined microscopically. As in the case of hard-wheat flours, the commercial grades, as indicated by percentages, varied markedly, and can be regarded only as approximate. The percentages ranged from 35 to 90 per cent. Some of the flours were bleached, others lightly bleached, and still others not bleached at all. Table 17 gives the results of this examination.

TABLE 17.—*Results of examination of patent flours milled from soft wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent patent."				
17161-L-A	(?)	Yes	72	10	82
17189-L-O	35	No	32	25	57
17167-L-FF	40	Yes	32	11	43
17165-L-EE	45	Yes	33	32	65
17132-L-U	60	No	19	1	20
17169-L-S	60	(?)	49	34	83
17187-L-V	60	No	23	17	40
15121-K-EE	65	Yes	50	12	62
15126-K-FFF	65	Yes	56	22	78
17133-L-FF	65	Yes	133	29	162
17161-L-LLL	67	No	46	19	65
17164-L-T	75-80	(?)	53	26	79
11007-K	90	(?)	51	30	81

The bran particle count varied from 19 to 133, the hair count from 1 to 34, and the total offal count from 20 to 162. The average count for bran particles was 49 and that for hairs 20, while the average total offal count amounted to 70.

PATENT FLOURS MILLED FROM BLENDED WHEATS.

The flours classified under blends were manufactured from mixtures of hard and soft wheats. Similar information was obtained for these flours as for the hard and soft types. The designations for the so-called grades varied from 70 to 85 per cent. Of the 12 samples examined, 4 were bleached and 8 unbleached. Table 18 gives the results.

TABLE 18.—*Results of examination of patent flours milled from blended wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent patent."				
11084-K	70	No	29	13	42
11085-K	70	Lightly	32	13	45
11086-K	70	Heavily	31	18	49
17159-L-V	70	No	20	15	35
17171-L-B	70	No	51	25	76
17168-L-YS	75	No	40	37	77
17168-L-YYH	75	No	18	13	31
17179-L-YY	80	No	36	19	55
17127-L-S	82	No	63	27	90
17116-L-D	83	Yes	61	40	101
17123-L-FF	85	Yes	47	21	68
17125-L-FF	85	No	83	17	100

The bran particle count ranged from 18 to 83, with an average of 42. The hair count ranged from 13 to 40, with an average of 21. The total offal count ranged from 31 to 101, with an average of 64.

PATENT FLOURS MILLED FROM MIDDLINGS STOCKS ONLY.

Information was obtained concerning the history of the mill streams entering into the composition of a large number of so-called patent flours. The data collected showed that middlings stocks only were employed in composing these flours. The results of the counts made on these samples are recorded in Table 19.

TABLE 19.—*Results of examination of patent flours milled from middlings stocks only.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent patent."				
17151-L-MM	40	(?)	19	13	32
15152-K-A	60	Yes	15	5	20
11070-K-FF	70	(?)	22	21	43
17154-L-AA	71	No	20	10	30
17158-L-X	71	Yes	19	13	32
15186-K-X	72	No	27	14	41
15174-K-LL	72	(?)	17	4	21
15170-K-CC	74	No	29	26	55
17144-L-FF	74	No	13	2	15
15181-K-S	80	Yes	17	19	36
15146-K-W	Short patent.	(?)	28	23	51
15163-K-R	(?)	Yes	16	8	24

Table 19 shows that the bran particle count ranged from 13 to 29, with an average of 20, that the hair count ranged from 2 to 26, with an average of 13, and that the total offal count ranged from 15 to 55, with an average of 33. These results demonstrate the fact that the purified middlings stocks employed had some effect upon the purity of the end-product. From the information the writers were able to obtain, however, so-called patent flours were not always composed of the best streams in the mill.

PATENT FLOURS MILLED FROM MIDDLINGS STOCKS PLUS LOWER-GRADE STOCKS IN THE MILL.

As already stated, stocks other than first-class middlings were often passed into patent flours. According to the information submitted, break flours and lower grades of middlings frequently were found to have been employed in the manufacture of the finished flour. The results recorded in Table 20 illustrate the effect of the addition of mill streams appreciably high in offal to the finished product.

TABLE 20.—*Results of examination of patent flours milled from middlings stocks in addition to lower-grade stocks in the mill.*

Sample No.	Commercial grade.	Variety of wheat.	Bleached.	Bran particles.	Hairs.	Total.
	"*Per cent.*"					
17189-L-O	35	Soft	No	32	25	57
17151-L-NN	52	Hard	No	72	45	117
17169-L-S	60	Soft	Yes	49	34	83
17133-L-FF	65	do	Yes	133	29	162
17161-L-LLL	67	do	No	46	19	65
17159-L-V	70	Blend	No	20	15	35
17171-L-B	70	do	No	51	25	76
15193-K-DD	75	Hard	Yes	30	39	69
15193-K-EE	75	do	No	33	36	69
17190-L-CC	75	do	Yes	66	33	99
17168-L-YYH	75	Blend	No	18	13	31
17164-L-T	75-80	Soft	Yes	53	26	79
17183-L-A	78	Hard	No	35	28	63
17184-L-Q	79	do	No	25	31	56
11064-K-A	80	do	No	54	28	82
17179-L-YY	80	Blend	No	36	19	55
17127-L-S	82	do	Yes	63	27	90
17147-L-BB	83	Hard	Yes	34	16	50
17156-L-FF	83	do	Yes	36	30	66
17116-L-D	83	Blend	Yes	61	40	101
17155-L-JJ	84	Hard	No	33	12	45
17123-L-FF	85	Blend	Yes	47	21	68
17125-L-FF	85	do	No	83	17	100
15135-K-CC	85	Hard	No	32	23	55
17180-L-JJ	94	do	Yes	62	34	96

The total offal count on these samples was consistently higher in most cases than the results obtained on samples ground from middlings stock only. The addition of break flour stocks appeared to have a marked effect upon their quality with respect to the offal count. The bran particles ranged in count from 18 to 133, with an average of 48. The hair count ranged from 12 to 45, with an average of 26. The total offal count varied from 31 to 162, with an average of 74.

GENERAL CONCLUSIONS ON PATENT FLOURS.

1. The commercial grades of so-called patent flours ranged from 35 to 90 per cent. These percentage figures apparently were intended to indicate that a certain percentage of the total flour content of the wheat kernel passed into this grade, the remainder being employed in other grades.

2. The average total offal count obtained on all commercial patent flours examined was 57.

3. Patent flours showed a marked variation in the total offal count obtained on different samples from various mills.

4. The limitations and the average counts on bran particles and hairs have been briefly summarized in Table 21.

TABLE 21.—*Limitations and average counts on bran particles and hairs for patent flours.*

Commercial grade.	Bran particles.		Hairs.	
	Variation.	Average.	Variation.	Average.
Hard-wheat patent	13 to 72	30	2 to 45	18
Soft-wheat patent	19 to 133	49	1 to 34	20
Blended-wheat patent	18 to 83	42	13 to 40	21

STRAIGHT FLOURS.

When only one grade of flour is manufactured in the mill, this grade is commercially designated as a straight flour, if it contains the entire flour content of the wheat that it is possible to mill. It might be considered to contain all of the flour that could be obtained from the wheat kernel with the exception of a certain percentage of so-called low-grade or red dog flour. Such a straight flour naturally would contain more of the branny particles from the wheat kernel than would a patent flour. The practice of compositing such a flour apparently varies in different mills. Tests were made upon a large number of straight flours milled from hard, soft, and blended wheats. The detailed information on these tests is given in the following paragraphs.

STRAIGHT FLOURS MILLED FROM HARD WHEATS.

Seventeen straight flours reported as having been milled from hard wheats were examined for their offal content. The commercial grades ranged from 92 to 100 per cent. The results of the examination appear in Table 22.

TABLE 22.—*Results of examination of straight flours milled from hard wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent straight."				
15196-K-U	92	No	33	34	67
11028-K-E	95	(?)	71	55	126
17157-L-B	95	Yes	50	45	95
17155-L-HH	96	Yes	89	33	122
15154-K-C	97	Yes	37	25	62
15106-K	97½	(?)	57	39	96
11067-K	98	(?)	62	31	93
15136-K-BB	98	Yes	55	51	106
15147-K	98	Yes	58	61	119
15191-K	98	(?)	62	87	149
15194-K-U	98	Yes	71	65	136
17113-L	98	Yes	63	19	82
17152-L-Y	98	(?)	57	26	83
17177-L-XX	98	No	71	47	118
11073-K-GG	100	(?)	76	61	137
17146-L-F	100	No	60	17	77
17186-L-F	100	No	121	22	143

The count obtained on bran particles ranged from 33 to 121 and that on hairs from 17 to 87. The average bran particle count was 64 and the average hair count 43. The total offal count ranged from 62 to 149, with an average of 106.

STRAIGHT FLOURS MILLED FROM SOFT WHEATS.

Seventeen straight flours reported to have been milled from soft wheats were examined. The commercial grades ranged from 90 to 100 per cent. Table 23 gives the results of this examination.

TABLE 23.—*Results of examination of straight flours milled from soft wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent straight."				
11096-K	90	No	52	40	92
11097-K	90	Lightly	41	31	72
11098-K	90	Heavily	56	38	94
15125-K-BB	90	Yes	92	58	150
15126-K-DDD	90	Yes	89	26	115
17166-L-Q	90	Yes	50	60	110
15125-K-FF	95½	Yes	111	70	181
15125-K-JJ	95½	No	119	54	173
17188-L-X	97	No	55	27	82
15125-K-Y	100	Yes	109	71	180
15125-K-OO	100	Yes	153	81	234
15126-K-AAA	100	Yes	93	40	133
17136-L-Z	100	Yes	97	22	119
17165-L-AA	100	Yes	109	34	143
17176-L-W	100	No	52	39	91
17185-L-H	100	No	34	34	68
17186-L-C	100	No	92	38	130

The bran particle count varied from 34 to 153, with an average of 82, and the hair count varied from 22 to 81, with an average of 45. The total offal count ranged from 68 to 234, with an average of 127.

STRAIGHT FLOURS MILLED FROM BLENDED WHEATS.

Eighteen samples of flour stated to have been milled from blends of hard and soft wheats were examined for their offal content, as in the case of the hard and soft types. The commercial grade designations varied from 90 to 100 per cent. The results of the examination are given in Table 24.

TABLE 24.—*Results of examination of straight flours milled from blended wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent straight."				
11087-K	90	No	50	26	76
11088-K	90	Lightly	51	22	73
11089-K	90	Heavily	50	28	78
17118-L-J	90	No	183	18	201
17173-L-V	90	Yes	21	36	57
11096-K	90	No	52	40	92
11097-K	90	Lightly	41	31	72
11098-K	90	Heavily	56	38	94
17120-L-N	96	Yes	90	47	137
17121-L-SS	97	No	98	30	128
11090-K	97½	No	42	28	70
11091-K	97½	Lightly	43	29	72
11092-K	97½	Heavily	52	26	78
17117-L-DD	97½	Yes	73	37	110
17115-L-E	96½	No	83	45	128
17173-L-W	98	No	33	47	80
15195-K-A	100	No	88	58	146
17128-L-Z	(?)	No	86	37	123

The bran particle count varied from 33 to 183, with an average of 68, while the hair count varied from 18 to 58, with an average of 34. The total offal count varied from 57 to 201, with an average of 100. The average total offal count obtained for the straight flours was 111, as against 57 for patent flours.

MILL STREAMS EMPLOYED IN THE MANUFACTURE OF CERTAIN STRAIGHT FLOURS.

Data were obtained on the mill streams employed in the manufacture of certain straight flours, and these streams were examined for their offal content for the purpose of illustrating the quality of the material sometimes used in making up such flours. The results are given in Tables 25, 26, and 27.

TABLE 25.—*Results of examination of mill streams employed in the manufacture of a straight flour (sample No. 17146–L–F) milled from hard wheats.*

Stock.	Bran particles.	Hairs.	Total.
First break	186	83	269
Second break	166	65	231
Third break	367	144	511
Fourth break	322	116	438
Fifth break	456	176	632
Second middlings	29	2	31
Third middlings	27	6	33
Third middlings (second stream)	13	4	17
Fifth middlings	21	5	26
Cut-off flour	15	4	19
Cut-off flour	76	18	94
Chunk flour	308	90	398
Second chunk flour	50	5	55
Tailings flour	76	24	100
Tailings flour	155	47	202
100 per cent straight flour [1]	60	17	77

[1] Composited from the mill streams listed above it.

TABLE 26.—*Results of examination of mill streams employed in the manufacture of a straight flour (sample No. 17165–L–AA) milled from soft wheats.*

Stock.	Bran particles.	Hairs.	Total.
First break	113	38	151
Second break	75	38	113
Third break	131	53	184
First, second, and third breaks	101	45	146
Fourth break	228	106	334
Fifth break	368	173	541
First middlings	21	8	29
Second middlings	48	27	75
Third middlings	26	7	33
Fourth middlings	29	2	31
Fifth middlings	55	12	67
Sixth middlings	60	18	78
Seventh middlings	143	23	166
Eighth middlings	264	38	302
First germ flour	50	5	55
100 per cent straight flour [1]	109	34	143

[1] Composited from the mill streams listed above it.

TABLE 27.—*Results of examination of mill streams employed in the manufacture of a straight flour (sample No. 17128–L–Z) milled from blended wheats.*

Stock.	Bran particles.	Hairs.	Total.
First break	334	162	496
Second break	150	83	233
Third break	118	53	171
Fourth break	118	50	168
Fifth break	296	101	397
First middlings	66	31	97
Second middlings	41	21	62
Third middlings	69	26	95
Fourth middlings	38	23	61
Fifth middlings	74	36	110
Sixth middlings	70	37	107
Seventh middlings	63	26	89
First sizings	56	11	67
Second sizings	107	34	141
First tailings	134	43	177
Second tailings	108	48	156
Head cuts	132	63	195
Tail cuts	130	70	200
Straight flour [1]	87	37	124

[1] Composited from the mill streams listed above it.

GENERAL CONCLUSIONS ON STRAIGHT FLOURS.

1. The commercial grades of so-called straight flours ranged from 90 to 100 per cent.

2. The average total offal count obtained on all commercial straight flours examined was 111.

3. Straight flours showed a decided variation in the total offal count obtained on different samples from various mills.

CLEAR FLOURS.

Clear flour, so-called, is often considered among millers as being a mixture of odds and ends of the milling stocks. Low grades of middlings and break flours often pass into it, although frequently it contains the purest quality of middlings stock from the tail of the mill. Clear flours which were said to have been milled from hard, soft, and blended wheats, respectively, were examined.

CLEAR FLOURS MILLED FROM HARD WHEATS.

Thirty-one clear flours stated to have been milled from hard wheats were examined. Their percentages ranged from 6 to 52. Table 28 shows the counts thus obtained.

TABLE 28.—*Results of examination of clear flours milled from hard wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent clear."				
17180-L-KK	6	Yes	331	132	463
17151-L-OO	8	No	238	166	404
17142-L-EE	10	No	306	50	356
17112-L-T	12	No	191	98	289
17150-L-U	12	No	197	77	274
15138-K-DD	13	No	156	126	282
17154-L-CC	14	No	294	223	517
17145-L-A	15	No	181	102	283
17147-L-AA	15	No	271	184	455
17175-L-NN	15	No	241	62	303
17183-L-B	16	No	193	136	329
17184-L-P	16	No	127	119	246
11065-K-A	18	(?)	65	39	104
11079-K-JJ	22	No	82	68	150
11079-K-KK	22	Yes	71	67	138
15169-K-DD	23	(?)	131	124	255
15192-K-FF	23	Yes	410	196	606
15186-K-Y	24	No	172	140	312
11028-K-C	25	(?)	193	204	397
15175-K-MM	25	(?)	158	102	260
17143-L-BB	25	No	316	71	387
17144-L-II	26	No	271	93	364
15115-K	27½	No	92	71	163
15116-K	27½	Lightly	79	57	136
15117-K	27½	Heavily	77	49	126
11071-K-EE	30	(?)	127	178	305
17186-L-E	30	No	268	43	311
15150-K-AA	35	Yes	118	133	251
15137-K-FF	33-35	(?)	126	114	240
15180-K-AA	18	(?)	151	147	298
17151-L-NN	52	No	72	45	117

The bran particle count on these samples varied from 65 to 331, with an average of 174. The hair count ranged from 43 to 223, with an average of 109. The total offal count varied from 104 to 517, with an average of 295.

CLEAR FLOURS MILLED FROM SOFT WHEATS.

Thirteen samples of clear flour reported to have been milled from soft wheats were examined, these samples varying from 5½ to 50 per cent as far as commercial grades are concerned. Table 29 gives the results obtained.

TABLE 29.—*Results of examination of clear flours milled from soft wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent clear."				
15122-K-AA	5½	Yes	243	155	398
15122-K-LL	5½	No	244	164	408
15126-K-EEE	5½	(?)	282	99	381
17178-L-AAS	20	No	137	66	203
17132-L-W	25	No	308	30	338
15122-K-DD	30	Yes	245	167	412
15122-K-MM	30	No	208	143	351
17160-L-D	30	Yes	235	44	279
17162-L-U	30	No	160	40	200
17133-L-EE	35	Yes	247	39	286
17167-L-GG	50	Yes	126	32	158
17186-L-B	50	No	177	68	245
11006-K	25	(?)	253	72	325

The bran particle count varied from 126 to 308, with an average of 218. The hair count ranged from 30 to 167, with an average of 86. The total offal count ranged from 158 to 412, with an average of 306.

CLEAR FLOURS MILLED FROM BLENDED WHEATS.

Twelve samples of flour stated to have been milled from blended wheats were examined. The commercial grades ranged from 10 to 30 per cent. Table 30 gives the results of the examination.

TABLE 30.—*Results of examination of clear flours milled from blended wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent clear."				
17179-L-ZZ	10	No	115	61	176
17116-L-E	15	No	127	65	192
17123-L-GG	15	No	250	73	323
17125-L-GG	15	No	297	40	337
17171-L-C	20	No	209	96	305
11093-K	27½	No	76	45	121
11094-K	27½	Lightly	55	49	104
11095-K	27½	Heavily	61	47	108
17182-L-II	30	No	166	142	308
17173-L-Y	40	No	112	98	210
17172-L-BB	50	Yes	88	44	132
17159-L-W	25	No	111	67	178

The bran particle count varied from 55 to 297, with an average count of 139, and the hair count varied from 40 to 142, with an average of 69. The total offal count varied from 104 to 337, with an average of 207.

MILL STREAMS EMPLOYED IN THE MANUFACTURE OF CERTAIN CLEAR FLOURS.

Tables 31 and 32 record the results obtained on certain mill streams which were employed in making up clear flours. As in the case of the commercial grades already considered, these figures are merely submitted to demonstrate the quality of the stocks that might be used in such a flour from the standpoint of offal material.

TABLE 31.—*Results of examination of mill streams employed in the manufacture of a clear flour (sample No. 17143-L-BB) milled from hard wheat.*

Stock.	Bran particles.	Hairs.	Total.
First and third breaks	310	59	369
Second break	324	42	366
Third break	628	107	735
Fourth break	810	213	1,023
First tailings	120	5	125
Second tailings	120	4	124
Third tailings	38	1	39
Fourth tailings	567	72	639
First germ flour	430	38	468
Second germ flour	560	33	593
First dustings flour	184	28	212
Third dustings flour	110	15	125
Dust collector material	575	99	674
25 per cent clear flour[1]	316	71	387

[1] Composited from the mill streams listed above it.

TABLE 32.—*Results of examination of mill streams employed in the manufacture of a clear flour (sample No. 11079–K–JJ) milled from hard wheat.*

Stock.	Bran particles.	Hairs.	Total.
First break	196	165	361
Third break (head)	120	121	241
Third break (tail)	100	103	203
Fifth middlings	28	24	52
Sixth middlings (head)	46	45	91
Sixth middlings (tail)	55	26	81
Seventh middlings (head)	56	27	83
First sizings	87	31	118
First tailings (head)	151	58	209
First tailings (tail)	87	32	119
22 per cent clear flour[1]	82	68	150

[1] Composited from the mill streams listed above it.

GENERAL CONCLUSIONS ON CLEAR FLOURS.

1. The commercial grades of so-called clear flours ranged from 5½ to 52 per cent.

2. The average total offal count obtained on all commercial clear flours examined was 273. This amount was decidedly in excess of the amount obtained on the commercial grades already considered.

3. As in the case of the other grades, clear flours showed a wide variation in the total offal count obtained on products from different mills.

LOW-GRADE FLOURS.

The low-grade flour is supposed to be made from low-grade mill stocks, as might be inferred from the designation applied to this class of products. As already stated, the better stocks, for the most part, are diverted into the higher grades. The streams entering into the composition of the low-grade flours are usually more or less specky, due to the presence of offal material. For this reason it is quite impossible to obtain an accurate count on such a flour. In fact, a casual microscopical examination is usually all that is necessary to determine the quality of the flour.

LOW-GRADE FLOURS MILLED FROM HARD WHEATS.

Eleven low-grade flours milled from hard wheats were examined, with the results shown in Table 33. The commercial grades ranged from 2 to 10 per cent, some of the samples being bleached and others unbleached.

TABLE 33.—*Results of examination of low-grade flours milled from hard wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent low-grade."				
11066–K	2	(?)	243	91	334
15118–K	2½	No	310	129	439
15119–K	2½	Lightly	340	131	471
15120–K	2½	Yes	310	112	422
15156–K–D	3	No	252	155	407
15148–K–X	2–5	No	175	88	263
11080–K–HH	5	No	353	301	654
11080–K–II	5	Yes	274	335	609
11029–K–D	8	(?)	269	264	533
11072–K–OO	6	(?)	169	163	332
11080–K–OO	10	Yes	317	238	555

The bran particle count varied from 169 to 353, with an average of 273. The hair count ranged from 88 to 335, with an average of 182. The total offal count varied from 263 to 654, with an average of 456.

LOW-GRADE FLOURS MILLED FROM SOFT WHEATS.

The eight samples of low-grade flour milled from soft wheats ranged from 2 to 10 per cent, with bleaching being practiced in some instances and not in others. Table 34 gives the results of this examination.

TABLE 34.—*Results of examination of low-grade flours milled from soft wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent low-grade."				
17136-L-Y	(?)	(?)	202	27	229
17185-L-G	(?)	No	143	257	400
17176-L-X	2	No	309	145	454
17188-L-W	3	No	238	261	499
15123-K-Z	4½	Yes	402	219	621
15126-K-CCC	4½	No	390	139	529
17178-L-BBS	6	No	307	124	431
17165-L-Y	10	Yes	331	80	411

The bran particle count varied from 143 to 402, with an average of 302. The hair count ranged from 27 to 261, with an average of 140. The total offal count varied from 229 to 621, with an average of 446.

LOW-GRADE FLOURS MILLED FROM BLENDED WHEATS.

Eight samples of flour stated to have been milled from blended wheats ranged in commercial grades from 1½ to 10 per cent, only one sample of the number being represented as having been bleached. The results of the examination are shown in Table 35.

TABLE 35.—*Results of examination of low-grade flours milled from blended wheats.*

Sample No.	Commercial grade.	Bleached.	Bran particles.	Hairs.	Total.
	"Per cent low-grade."				
17123-L-EE	(?)	No	394	59	453
17128-L-T	(?)	No	100	61	161
17117-L-Y	1½	No	211	76	287
17115-L-F	3½	(?)	357	141	498
17120-L-J	4	No	397	183	580
17171-L-D	5	No	237	94	331
17172-L-AA	10	Yes	281	131	412
17179-L-AAA	10	No	262	132	394

The bran particle count had limitations of from 100 to 397, with an average of 279. The hair count varied from 59 to 183, with an average of 109. The total offal count ranged from 161 to 580. with an average count of 389.

GENERAL CONCLUSIONS ON LOW-GRADE FLOURS.

1. The commercial grades of so-called low-grade flours ranged from 2 to 10 per cent.

2. The average total offal count obtained on all commercial low-grade flours examined was 433. This indicated that not as much attention was given to the purification of the stocks passing into such flours as was done in the case of the stocks composing the grades already considered.

3. The data obtained on the low-grade flours milled from the different wheats are summarized in Table 36.

TABLE 36.—*Limitations and average counts on bran particles and hairs for low-grade flours.*

Type.	Bran particles.		Hairs.	
	Variation.	Average.	Variation.	Average.
Hard wheat	169 to 353	273	88 to 335	182
Soft wheat	143 to 402	302	27 to 261	140
Blended wheat	100 to 397	279	59 to 183	109

EXAMINATION OF EXPERIMENTAL SERIES OF FLOUR.

In connection with the examination of commercial flours it was considered advisable to examine samples of flour whose composition was definitely known, as far as the wheat from which they were milled and their constituent streams were concerned. The information in regard to the commercial samples was definite enough in so far as the milling operator was able to judge.

The samples of flour employed in this part of the investigation were milled under the personal supervision of B. C. Winslow, food and drug inspector, Bureau of Chemistry, United States Department of Agriculture. The samples were prepared at a plant at Lyons, Kans., a portion being milled from a No. 2 Nebraska hard winter wheat, crop of 1914, containing from 25 to 35 per cent of yellow berry wheat, and another portion from a Kansas No. 2 hard winter wheat. Each type of flour was subjected to three degrees of bleaching, thus making three samples for each type. Four types of flour were made from each wheat, a 70 per cent, a 90 per cent, a 97.5 per cent, and a 27.5 per cent. In the case of the Kansas wheat a fifth type, a 2.5 per cent, was made. The component streams that passed into each type and the results of the examinations made were as follows:

THE 70 PER CENT TYPE OF EXPERIMENTAL FLOUR.

COMPOSITION.

First sizings flour.
Second sizings flour.
First middlings flour.
Second middlings flour.
Third middlings flour.
Fourth middlings flour.
Fifth middlings flour.
Fine tailings flour.
Coarse tailings flour.

TABLE 37.—*Results of examination of 70 per cent type of experimental flour.*

Wheat.	Sample number.	Degree of bleaching.	Bran particles.	Hairs.	Total.
No. 2 Nebraska, hard winter.	11084-K	None	29	13	42
	11085-K	Lightly	32	13	45
	11086-K	Heavily	31	18	49
No. 2 Kansas, hard winter	15112-K	None	10	12	22
	15113-K	Lightly	12	9	21
	15114-K	Heavily	(1)	(1)	(1)
Average count			22	13	35

[1] Not counted; infested with weevils.

THE 90 PER CENT TYPE OF EXPERIMENTAL FLOUR.

COMPOSITION.

First sizings flour.
Second sizings flour.
First middlings flour.
Second middlings flour.
Third middlings flour.
Fourth middlings flour.
Fifth middlings flour.
Fine tailings flour.
Coarse tailings flour.
Second break flour.
Third break flour.
Fourth break flour.
Sharp section (middlings).
Cut-off flour (middlings).
Sixth middlings flour.
Seventh middlings flour.
Eighth middlings flour.

TABLE 38.—*Results of examination of 90 per cent type experimental flour.*

Wheat.	Sample number.	Degree of bleaching.	Bran particles.	Hairs.	Total.
No. 2 Nebraska, hard winter.	11087-K	None	50	26	76
	11088-K	Lightly	51	22	73
	11089-K	Heavily	50	28	78
No. 2 Kansas, hard winter	15109-K	None	32	31	63
	15110-K	Lightly	31	28	59
	15111-K	Heavily	28	34	62
Average			40	28	68

THE 97.5 PER CENT TYPE OF EXPERIMENTAL FLOUR.

COMPOSITION.

First sizings flour.
Second sizings flour.
First middlings flour.
Second middlings flour.
Third middlings flour.
Fourth break flour.
Sharp section (middlings).
Cut-oft flour (middlings).
Sixth middlings flour.
Seventh middlings flour.
Fourth middlings flour.
Fifth middlings flour.
Fine tailings flour.
Coarse tailings flour.
Second break flour.
Third break flour.
Eighth middlings flour.
First break flour.
Fifth break flour.
Ninth middlings flour.
Flour from dust-collecting reels.

TABLE 39.—*Results of examination of 97.5 per cent type of experimental flour.*

Wheat.	Sample number.	Degree of bleaching.	Bran particles.	Hairs.	Total.
No. 2 Nebraska, hard winter.	11090-K	None	42	28	70
	11091-K	Lightly	43	29	72
	11092-K	Heavily	52	26	78
	15106-K	None	57	39	96
	15107-K	Lightly	43	29	72
	15108-K	Heavily	28	30	58
Average			44	30	74

THE 27.5 PER CENT TYPE OF EXPERIMENTAL FLOUR.

COMPOSITION.

Second break flour.
Third break flour.
Fourth break flour.
Sharp section.
Cut-off flour (middlings).
Sixth middlings flour.
Eighth middlings flour.
First break flour.
Fifth break flour.
Ninth break flour.
Flour from dust collectors.
Seventh middlings flour.

TABLE 40.—*Results of examination of 27.5 per cent type of experimental flour.*

Wheat.	Sample number.	Degree of bleaching.	Bran particles.	Hairs.	Total.
No. 2 Nebraska, hard winter.	11093-K	None	76	45	121
	11094-K	Lightly	55	49	104
	11095-K	Heavily	61	47	108
No. 2 Kansas, hard winter	15115-K	None	56	65	121
	15116-K	Lightly	49	51	100
	15117-K	Heavily	51	40	91
Average			58	49	107

THE 2.5 PER CENT TYPE OF EXPERIMENTAL FLOUR.

COMPOSITION.

Bran duster flour.
Cut-off flour from seventh middlings.
Shorts duster flour.
Cut-off flour from ninth middlings.

TABLE 41.—*Results of examination of 2.5 per cent type of experimental flour.*

Wheat.	Sample number.	Degree of bleaching.	Bran particles.	Hairs.	Total.
No. 2 Kansas, hard winter	15118-K	None	310	129	439
	15119-K	Lightly	340	131	471
	15120-K	Heavily	310	112	422
Average			320	124	444

GENERAL CONCLUSIONS ON EXPERIMENTAL TYPES OF FLOUR.

The best grade of flour of the experimental series averages a little lower in total offal count than the best grade in the commercial set, being 57 for the commercial flours and 35 for those of the experimental set. The two intermediate grades of the commercial flours were higher in the offal count than similar grades in the experimental series, the count being 111 and 273 for the commercial flours and 71 and 107 for those of the experimental set. Both of the lower-grade flours, that from the commercial and experimental sets, respectively, compared very favorably as far as the offal count was concerned, these figures being essentially minimum ones although approximately representative of the two products.

SUMMARY.

1. Microscopical technique was devised for the enumeration of the offal material in flour of various commercial grades.

2. The data obtained on the various commercial grades of flour demonstrated that there was little uniformity in the matter of grading finished flours in different mills.

3. The experimental data submitted have shown a wide range in the offal content among flours of the same commercial grade (apparently) produced by different mills.

4. The information obtained concerning the samples examined leads to the inference that all mills do not composite finished flours in the same manner.

5. The microscopical examination of the constituent streams entering into the composition of a finished flour shows the effect of the addition of different mill stocks on the resulting offal content.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 840

Contribution from the Office of Farm Management.
H. C. TAYLOR, Chief.

Washington, D. C. ▼ April 27, 1920

A SYSTEM OF RECORDS FOR LOCAL FARMERS' MUTUAL FIRE INSURANCE COMPANIES.

By V. N. VALGREN, *Investigator in Agricultural Insurance.*

CONTENTS.

INTRODUCTION.

There are nearly 2,000 farmers' mutual fire insurance companies in the United States. Most of these farmers' mutuals are strictly local concerns, confining their business to a single county or at most a few adjoining counties. Many even limit themselves to a fraction of a county. These companies, generally speaking, have been very successful, and they are saving the farmers of the country a large sum of money every year by reason of the relatively low cost at which they furnish insurance protection.

One of the greatest needs of a large percentage of these companies is a system of records which is simple and sparing in its demands upon the time and effort of the secretary, and yet makes readily available all necessary information concerning the business of the company. This need has been emphasized on many occasions by officers of farmers' mutuals. The desire for greater uniformity in the records of these companies has frequently been expressed also by supervising State officials as well as by the companies' officers gathered in conventions of State or national associations.

NOTE.—Acknowledgment is due Messrs. G. A. Nahstoll and A. V. Swarthout, investigators in market business practice, of the Bureau of Markets, for suggestions embodied in this bulletin.

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The system outlined and illustrated in this bulletin is intended for farmers' mutual fire insurance companies of the prevailing type both as to membership or size and as to method of doing business. It is the result of a careful study of the needs of these companies and of the forms and systems of records now in use. In this connection numerous conferences have been had with experienced secretaries and managers. It is believed, therefore, that the system recommended will meet the needs of these companies, and that it will aid in bringing about a reasonable degree of uniformity.

SYSTEMS NOW IN USE.

While the present methods of keeping records and accounts are almost as numerous as the companies, they may be roughly classified into three groups, according to the plan of keeping the main insurance records, in what is most frequently called the policy register. The three methods of keeping the policy register, which are characteristic of these groups, may be briefly described as follows:

I. The policy register, either permanently bound or in loose leaf form, contains a description of the policies written on a horizontal line extending across one page only, or across the two pages of the open book. The right-hand page of the book frequently contains spaces for entering a limited number of successive assessments. In other instances this latter feature is lacking and separate assessment lists are made out for each assessment levied. In some cases the various sums of insurance applying to specific units or groups of property are recorded in this book, while in other cases it contains only the total amount of each policy, together with such necessary items as number of policy, name of policy holder, etc.

II. The policy register is in what may be termed the ledger form. Under this plan each member is allotted a page or half a page in this book. The upper part of the space allotted to a member contains the entries descriptive of the policy, either with or without an itemized transcription of the insurance carried, while the lower part of the space provides a place for debits and credits.

III. A card system is used for the policy records. The main difference between this plan and that referred to under II is that the records relating to a single member are entered on a card about the size of a page in this bulletin, instead of on a ledger page. As a rule the cards are filed alphabetically, thus eliminating the need for a separate index book or set of index cards.

SYSTEM RECOMMENDED.

The system here suggested is built upon Plan I, as above outlined, since this form of policy register, when accompanied by certain other simple but necessary books, is believed to combine to the greatest extent the essentials of simplicity and convenience with a maximum of readily available information.

Plan II necessitates a considerable amount of posting or transcribing of items from the policy register to a book of summary accounts or a general ledger. It therefore presupposes a more thorough knowledge of bookkeeping principles, and requires a certain amount of additional clerical work. A book of ordinary size soon becomes filled if a page, or even half a page, is allotted to each member. Hence the records become bulky and require a relatively large safe for their accommodation.

In spite of the many advantages claimed for the card system of records, here referred to as Plan III, only a few farmers' mutual insurance companies have adopted it and some of these have expressed their intention to return to the book form of records. The secretary of a farmers' mutual, in a very large percentage of cases, is neither a trained bookkeeper nor an accountant, but rather a practical farmer by experience who has been induced to devote a part or all of his time to the local insurance company. Under these circumstances it seems that the tendency for a card record to become lost or misplaced more than offsets the convenience with which such records can be systematically arranged, dead records removed, additional records inserted, etc. The essential disadvantages of Plan II in the way of necessary posting or summarizing can also be charged against Plan III. For these reasons Plan I, which is at present the prevailing plan, has been used as a basis for the system here suggested, each book of which will be found briefly described as well as illustrated in the following pages. The books comprise a policy register, a book for increases and cancellations, a cash receipts book, a cash disbursements book, and an index book, or its equivalent in a set of index cards. To these books, each of which is practically indispensable to the keeping of complete records and the avoidance of needless labor and confusion, there have been added two books intended to make possible the keeping of a historical summary of the company's business in condensed form. One of these provides for a periodic summary of policies and risks and the other for a similar summary of receipts, disbursements, and balances or cash on hand. A general ledger and various other books will of course be needed by the larger mutuals, which, as a rule, employ trained bookkeepers, but it is thought best not to complicate this discussion with considerations involving technical bookkeeping or accounting.

POLICY REGISTER.

The policy register suggested allows for each policy two horizontal lines or spaces running across the two facing pages of the open book. In the forms intended for actual use the two spaces intended for the record of a single policy should be separated by a faint line, while

Form 1. Left Hand Page

POLICY REGISTER

Policy Number	Name and Address	Location of Property	Application Taken By	Insurance: Original Policy, Amount	Insurance: Original Policy, Date	Insurance: Increases, Amount	Insurance: Increases, Date	Insurance: Cancellations, Amount	Insurance: Cancellations, Date	Insurance by Class: Class A	Insurance by Class: Class B	Insurance by Class: Class C	Insurance by Class: Class D	Insurance by Class: Class E	Mortgage Clause Attached Date and Mortgagee
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
526	L S Simons	SE¼ SW¼			1918										
	Carson Route 2	Sec 8 T 104	L C J	2600	Jan. 12							950	1650		
527	E C Jones	NE¼ SE¼											1600		
	Shelby	Sec 10 T 103	M L	2950	Mar 7	200	Dec 7 '18				1100	450	X ~~400~~		
528	J H Mason	½ Mi N.												300	
	Carson	of Carson	L C J	2100	Mar 20			100	Jan 5 '19			725	975	~~400~~	

Form 1 Right Hand Page

POLICY REGISTER

INITIAL CHARGES AND ASSESSMENT BASIS						ASSESSMENT NO. 1 DATE OF LEVY Oct. 20 1918		ASSESSMENT NO. -- DATE OF LEVY --- 19--		ASSESSMENT NO. -- DATE OF LEVY --- 19--		ASSESSMENT NO. -- DATE OF LEVY --- 19--		ASSESSMENT NO. -- DATE OF LEVY --- 19--		MEMORANDA
ON ORIGINAL POLICY		ON INCREASES		DECREASE IN ASS'M'T BASIS BY CANCEL-LATION	NEW ASSESSMENT BASIS											
POLICY FEE	INITIAL PREMIUM	POLICY FEE	INITIAL PREMIUM			AMOUNT	DATE OF PAYMENT	AMOUNT	DATE OF PAYMENT	AMOUNT	DATE OF PAYMENT	AMOUNT	DATE OF PAYMENT	AMOUNT	DATE OF PAYMENT	
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1 50	7 83					7 83	Nov. 10									
1 50	7 95	50	66		8 61	7 95	Nov. 5									
1 50	6 63			40	6 23	6 63	Nov. 8									

these pairs of spaces are in turn separated by a more pronounced line. The sample pages here given (Form 1, left-hand page and right-hand page) provide room for recording only 10 policies. In practice the pages should be made long enough for the record of 20 policies. For convenience in tracing the record of a given policy across the double page, the horizontal lines separating each group of five double spaces should be ruled extra heavy or in a color distinct from the other horizontal lines.

It will be noticed that the left-hand page of Form 1 is, in general, devoted to the description of the policy, while the right-hand page provides space for the recording of fees and assessments. The headings of the various columns are believed to be self-explanatory. More than two-thirds of the farmers' mutuals write policies regularly for a term of five years, and partly for this reason no special column has been provided for the date of expiration. In cases where the company writes policies for varying periods of time, and the expiration for this reason is not readily ascertainable from the date of the policy, the upper half of column 6 may be used for the date of the policy and the lower half for the time of expiration.

The left-hand page of Form 1, it will be seen, includes spaces for recording property insured by classes, as well as for the total amount of the policy. A strict adherence to bookkeeping principles would require that extra columns for increases and cancellations be provided in connection with each of the five class columns in Form 1, as well as in connection with the column for the total amount of insurance. Since to do so would make the pages unduly wide, however, and since the changes in a given class column will be relatively less frequent than in the column for total insurance, it was deemed advisable to handle changes in the class columns by the simple plan of crossing out the superseded figures and entering the corrected item above, as shown in two of the sample entries. The columns for insurance by class in the policy register do not need to be refooted to show net amounts after increases or cancellations have been recorded, since these items can be obtained for the period in question from the special book for increases and cancellations.

While only a relatively small number of the farmers' mutuals at present classify their risks, it is becoming recognized to an increasing extent that justice as well as expediency demands such classification.[1]

[1] Under the all-one-rate plan the owners of the better class of risks pay part of the insurance cost of the owners of the more hazardous class of risks. Larger companies which do classify can underbid a local mutual which does not classify, on the most desirable risks in the territory of the latter, even though the average insurance cost be considerably higher in the larger company. Lastly, a proper classification constitutes one of the most effective means that a company can employ for the improvement of the risks in its territory, and hence for the further reduction of its insurance cost as well as for the conservation of the property of its members.

A suggested plan of classification of farm property may be found in Department Bulletin 530, entitled, "The Organization and Management of a Farmers' Mutual Fire In-

Assuming that classification is either now practiced, or is contemplated for the near future, the books should provide space for a summary of insurance in force by classes as well as for total amount of risks carried. This is necessary in order that the relative rates adopted for the different classes may be checked up by experience and altered if found to be inequitable.

The initial premium, which must in any case be recorded, and for which space has been provided in column 18 of the policy register (Form 1, right-hand page), should constitute the assessment basis, taking the place of the amount of insurance, or what is frequently called the face of the policy, for this purpose. Where the suggestions contained in the footnote, page —, are followed, the actual calculation of an assessment against a given policy is simplified rather than complicated by this method.

When an increase in a given policy or a cancellation therefrom has been made, however, it becomes necessary to arrive at a new assessment basis by the proper addition, as indicated in column 20, or by the proper deduction, as indicated in column 21 of the form referred to. The adjusted assessment basis is recorded in column 22. Each policy is assessed upon the basis of the initial premium recorded in column 18, unless by reason of changes in the amount or classification of the insurance a new assessment basis has been calculated for the policy and recorded in column 22.

More than two-thirds of the existing farmers' mutuals, as already stated, write their policies for a period of five years. It will be noticed that space has been provided for five successive assessments against a policy. If the plan of charging one year's cost in advance, as suggested in Department Bulletin 530, is followed, however, only four assessments will normally be levied against a five-year policy. Under these circumstances the fifth assessment column may be reserved for a special assessment in case it should be found necessary or desirable to levy one.

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surance Company." The general plan of classification therein outlined has been indorsed by the National Association of Mutual Insurance Companies. While usable as a basis for classification by farmers' mutuals located in different parts of the country, it should be modified, wherever necessary, to meet local conditions.

One of the most common objections to a classification of risks has been based upon the feeling that it would complicate the levying of assessments. This objection has been removed, it is believed, by the plan outlined in Department Bulletin 530, namely, that of levying the assessments upon the basis of initial premiums collected, instead of upon the amount of insurance carried. Where the initial premium rates have been properly adjusted this plan is entirely equitable, and it is fully as simple as the plan of calculating assessments upon the amount of the policy In the absence of legal provisions prohibiting or unduly restricting advance assessments, such initial premiums may properly cover approximately one year's cost of insurance. Assuming that such is the case, the directors, instead of voting an assessment of 25 cents per $100 of insurance, as might have been done under the old plan, call for an assessment of 90, 100, 120, or some other per cent of the initial premium.

INCREASES AND CANCELLATIONS.

The keeping of a special book for increases and cancellations, while adding no data not already contained in the policy register, is nevertheless highly important. Its value lies in the convenience that such a book offers in making up a summary of the business for any given period. Such a summary is necessary at least once a year, when the report to the State insurance supervisor and to the members gathered in annual meeting is called for, and it is likely to be desired at least quarterly, if not monthly, by the officers and directors of the company. In the preparation of such a summary the amount of insurance written in the form of new policies issued is easily found from the main record book. Similarly the amount which has regularly expired may be ascertained by the relatively simple process of finding the net amount (original amount, plus increases, less cancellations) of a consecutive list of policies in the policy register. The amounts added to or canceled from existing policies during the year or other period for which a report is desired, however, will be scattered over a considerable number of pages in the policy register, since these adjustments are made not only in policies written during the year in question, but also in policies one, two, three, or more years old, depending on the term for which insurance is written by the company. To go through the list of all these policies in the main record book and pick out the changes that apply to the current period becomes a tedious task. A special book for increases and cancellations makes the process of summary one of mere addition of columns of figures without any tedious search for the items to be taken into account. This convenience more than offsets the extra work involved in the double entry of increases and cancellations.

In the models for this book (Form 2, left-hand page and right-hand page) provision has again been made for keeping the record by classes as well as for recording the total amount of increases and cancellations.

CASH RECEIPTS AND DISBURSEMENTS.

The cash-receipts book (Form 3), and the cash-disbursements book (Form 4) contain special columns for such classes of items as frequently occur, and a catch-all column for such items of receipts or disbursements as occur only rarely. Such a plan saves much work when a detailed report of the company's affairs is to be prepared. The column headings in these books are believed to be serviceable for most companies, though it is advisable to consult the blanks furnished for annual reports by the insurance supervisor of the State in which the company operates, before deciding upon the exact headings to be used for these columns.

While it is the general custom to combine Forms 3 and 4 into a cash book, the receipts occupying the left-hand page and the disbursements the right, this plan is very wasteful of space on the disbursement side when followed by a mutual insurance company. The receipts in this business consist of a large number of small sums, while the disbursements, of which losses constitute as a rule the most important class, consist in general of much larger sums correspondingly few in number. Only by using a smaller desk book for the recording of the daily receipts and then transferring the footings of the pages in this book to a regular cash book is it possible without undue waste of space to have receipts and disbursements on opposite pages in a regular cash book. Some secretaries actually follow this latter plan but it has been avoided here in order that the forms and methods presented may be as few and simple as practicable.

In the cash-receipts book should be recorded every individual cash item received by the company. A representative of the company may, of course, send in at one time a sum representing a dozen or more individual fees and premiums and there may be a temptation to reduce the number of entries by recording only the total sum received. To do so, however, is to make difficult the checking of the fees, premiums, and assessment items in the cash-receipts book against the same items as recorded in the policy register, and such checking becomes necessary in case the totals for the corresponding items in the two books do not agree.

ANNUAL REPORT.

The main data wanted for an annual report in the case of a farmers' mutual fire insurance company are as follows: Cash on hand at the beginning of the year; cash receipts and cash disbursements during the year, both properly itemized; cash on hand at the end of the year; amount of insurance in force at the beginning of the year; amount of insurance written during the year; amount of insurance which has expired or been canceled during the year; and net amount of insurance in force at the end of the year.

The cash on hand at the beginning of the year will, of course, be the same as cash on hand at the close of the preceding year. The itemized cash receipts during the year will be found by adding up the various columns in the cash receipts book and the sum of these amounts will represent the total receipts during the year. Similarly, by adding up the columns in the cash disbursements book, the losses during the year as well as the amounts paid for expenses of the various kinds indicated by the column headings will be found, and the sum of these amounts will represent total disbursements during the year. To the cash on hand at the beginning of the year is then added the total receipts during the year, and from this sum is subtracted the total disbursements. The amount thus obtained represents the cash on hand at the close of the year.

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Form 2, Left Hand Page

INCREASES

POLICY NUMBER	AMOUNT OF INCREASE	DATE	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	POLICY FEE	INITIAL PREMIUM	MEMORANDA
1	2	3	4	5	6	7	8	9	10	11
527	200	Dec. 7, 1918				200		50	66	On Live Stock

Form 2. Right Hand Page

CANCELLATIONS

POLICY NUMBER	AMOUNT CANCELLED	DATE	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	ADVANCE CHARGES RETURNED	DECREASE IN ASSESSMENT BASIS	MEMORANDA
12	13	14	15	16	17	18	19	20	21	22
528	100	Jan. 5, 1919					100		40	On Barn

Form 3

CASH RECEIPTS

DATE	EXPLANATION	POLICY FEES	INITIAL PREMIUMS	ASSESSMENTS	FEES OTHER THAN POLICY FEES	INTEREST RECEIVED	ALL OTHER RECEIPTS
1	2	3	4	5	6	7	8

Form 4

CASH DISBURSEMENTS

DATE	EXPLANATION	NUMBER OF VOUCHER	DIRECTORS PER DIEM AND MILEAGE	OFFICERS' SALARIES	AGENTS OR DIRECTORS APPLICATION FEES	LOSSES	ALL OTHER DISBURSEMENTS
1	2	3	4	5	6	7	8

Occasionally it will be found necessary or desirable to make a more detailed subdivision of the items found in the columns headed "All other receipts" and "All other disbursements," respectively. Since the entries in these columns in the case of the average farmers' mutual will be relatively few, such further classification of these items will involve but a small amount of work.

The method of ascertaining the amount of insurance in force has already been referred to in connection with the book for increases and cancellations. It may be briefly summarized at this point. The amount of insurance in force at the beginning of the year will be the same as amount in force at the end of the previous year. The amount of insurance written will be found by adding to the sum of the figures in column 5 of the policy register entered during the year the sum of the figures in column 2 of the record of increases (Form 2, left-hand page).

The net amount of insurance which has expired during the year, by virtue of the termination of the period for which it was written, will be found from the appropriate sections of columns 5, 7, and 9 in the policy register. Assuming that policies are written for a uniform period of five years, as is the case with more than two-thirds of the farmers' mutuals, the net amount of expirations during 1919, for example, will be the sum of the original amounts of the policies written during 1914, plus the sum of any increases made to these policies, less the sum of any cancellations therefrom, as shown in columns 5, 7, and 9, respectively, in the policy register. To this net amount of expirations is then added the sum of all cancellations during the year, as shown in column 13 of the special book for increases and cancellations, which column should include all cancellations, whether of parts of policies or of entire policies the regular period of existence of which has not yet elapsed. The sum thus obtained will represent the total amount which has expired or been canceled during the year.

The amount written during the year is then added to the net amount in force at the beginning of the year, and from this sum is subtracted the amount which has expired or been canceled during the year. The difference represents the net amount in force.

Similarly, the amount in force in each class may be found by adding to the amount in force in that class at the beginning of the year, the amount written in that class during the year as a part of original policies, plus the amount of all increases in the class for the same period. From this sum is then subtracted the amount in the same class which has expired or been canceled during the year. The sum of the net amounts obtained for the several classes should again give the net amount which the company has in force, and should, of course, agree with the amount obtained by the first process.

The cash receipts and disbursements are in little need of explanation from the point of view of making out a report. It may be pointed out, however, that a check upon the accuracy of the most important items of receipts is to be found in the policy register. The policy fees and initial premium in columns 17 and 18 of the policy register for the period in question, plus the policy fees and initial premiums, respectively, in columns 9 and 10 of the record of increases (Form 2, left-hand page) for the same period should, of course, equal the corresponding receipt items in the cash receipts book, proper allowance having been made, when necessary, for fees and premiums reported but not yet remitted by those receiving applications for insurance. Similarly, the assessment column in the policy register, which was filled out before notices of assessment were sent, should balance the amount of the assessment column in the cash-receipts book, allowance having been made for any assessments not yet paid.

What has been said concerning the procedure in the preparation of an annual report will apply also to the preparation of a summary of the business for any other period of time, such as three months, one month, a week, or a single day.

INDEX OF POLICY-HOLDERS.

To facilitate the finding of a policy record when the name of the member but not the policy number is at hand, it is necessary to have some form of index. As the system of records here suggested is intended for the farmers' mutual of ordinary size, only a relatively simple index system need here be considered. Such an index system can be provided for, either by an index book with a page or a few pages given to each group of names coming within a given range of the alphabet, or by an alphabetical card system. To avoid a possible confusion of names, however, and for further convenience in locating a record, not only the policy number, but also the address of the policy-holder and the page of the policy register on which the record of his policy is found, should be recorded in the index book, or on the card.

In a small company using a book for index purposes, the grouping of names may be based on the first letter of the names only. For companies with 500 or more members it is desirable to make somewhat smaller groups. Assuming that the book used as an index contains at least 120 pages, two facing pages may be allotted to names belonging to each of the following alphabetical groups as determined in general by the first two letters of the names: Aa–Al, Am–Az, Ba, Be, Bi–Bo, Br, Bu–By, Ca–Ce, Ch–Cl, Co–Cz, Da, De–Di, Do–Dy, Ea–Em, En–Ez, Fa–Fi, Fo–Fy, Ga–Gh, Gi–Go, Gr–Gy, Ha, He, Hi, Ho, Hu–Hy, I, Ja–Ji Jo–Jy, Ka–Kl, Kn–Ky, La–Le, Li–Ly, McA–McL, McM–

McZ, Ma, Me–Mi, Mo, Mu–My, Na–Ni, No–Ny, O, Pa–Pl, Po–Py, Q, Ra–Ri, Ro, Ru–Ry, St.–Sa, Sc–Si, Sk–So, Sp–Sy, Ta–Th, Ti–Ty, U–V, Wa, We, Wh, Wi–Wo, Wr–Wy, X–Z. The sets of guide letters should be carefully written or printed near the upper outside corners of the pages which are assigned to them, respectively. It is also an easy matter to provide labeled tabs for the edges of the appropriate leaves so that the book may be opened, in one movement, at the pages containing the group of names desired.

Under this plan Adams, for example, would be listed in the first group, Aa–Al; Barber would be listed in the third group, Ba; Blair in the fifth group, Bi–Bo; etc. Any other alphabetical grouping more or less detailed than the one given above can, of course, be used. In general, the larger the company the more detailed should be the grouping. Form 5 shows a simple and convenient form for an index book.

Few existing farmers' mutuals, as already stated, favor the card system so far as the policy register is concerned. For the index system, however, the card plan has proven fairly popular. Since it is rarely necessary to remove the index cards from their regular place, the danger of misplacement of such cards is considerably less than is the case with cards used as a policy register. Index cards 3 by 5 inches in size can easily be obtained. The cards for this purpose may be ruled as shown in Form 6. Guide cards can also be secured with sets of guide letters printed thereon, similar to those suggested above. The guide cards should be of the so-called one-fifth cut, so that the tabs on the cards containing the guide letters stand in five rows across the card drawer and are all readily visible when the drawer is open.

PERIODIC SUMMARIES.

The forms described will make available, when properly used, all the current information necessary for the farmers' mutual of the prevailing type. The provision of two more books is desirable, however, as a means of keeping in convenient and condensed form the insurance and financial history of the company. Form 7, left-hand page and right-hand page, provides for periodic summaries of policies and risks, while Form 8, left-hand page and right-hand page, provides for similar periodic summaries of receipts and disbursements, together with the cash balance at the end of each period. Both forms may be used for daily, monthly, quarterly, and annual summaries as desired.

Some of the farmers' mutuals at present make a complete summary of their business only at the end of the year, at which time, as a rule, a report is required by the State insurance department. Frequently the only form used for an office record of such summary is an extra

Form 5

INDEX BOOK

NAME OF POLICY HOLDER	ADDRESS	POLICY NUMBER	PAGE
1	2	3	4
Simons, L. S.	Carson, Route 2	526	24

Form 6

INDEX CARD

Simons L. S. NAME			
Carson Route 2 ADDRESS	POLICY NUMBER	PAGE	
	526	24	

copy of the report blank furnished by the above-mentioned department. Other companies make quarterly summaries, and yet others also make monthly summaries. With suitable forms available it requires but little extra work to check up the business fully each month and to combine the monthly figures into quarterly summaries, from which in turn the figures for the annual report are easily obtained. This practice will frequently save considerable time and worry by the detection of errors while their probable location is confined to a comparatively few sets of figures, and while the incidents connected with the figures are relatively fresh in the mind of the record keeper.

Assuming that it is decided to make monthly and quarterly as well as annual summaries, the figures for the monthly summaries will of course be taken from the books of original record. A quarterly summary, however, would be arrived at by the simple process of combining three monthly summaries. In making such a quarterly summary for policies, on the left-hand page of Form 7, the sum of the three monthly entries in column 4, after being properly recorded, would be added to the earliest of the three entries in column 3, and the amount entered in column 5. The sum of the three monthly entries in column 6 would then be subtracted from the quarterly figures in column 5 and the difference entered in column 7, as representing the number of policies in force at the end of the quarter. The quarterly summary for risks or amounts of insurance would be ascertained by a corresponding process.

In making a quarterly summary for receipts and disbursements on Form 8, the three sets of monthly entries in the columns 4 to 10, inclusive, are added and the sum recorded for each column. The amount of these sums, after being checked against the sum obtained by adding the three monthly totals as found in column 11, is then entered in this column as total receipts for the quarter. This latter sum, namely, the total receipts, is then added to the earliest of the three monthly entries in column 3, representing cash on hand at the beginning of the period, and the amount of these two sums is recorded in column 12. The three sets of monthly entries in each of the columns 13 to 20, inclusive, are then added and the amount of these sums, after being checked in a manner corresponding to that suggested for total receipts, is then entered in column 21 as total disbursements for the quarter. Finally, the total disbursements are subtracted from the quarterly figures in column 12 and the difference entered in column 22 as cash on hand at the end of the quarter.

The quarterly summary figures should be entered in ink of a color which clearly distinguishes them from the monthly figures from which they are derived.

Form 7. Left Hand Page

SUMMARY OF POLICIES & RISKS

PERIOD COVERED		NUMBER OF POLICIES				
FROM	TO	IN FORCE AT BEGINNING OF PERIOD	WRITTEN DURING PERIOD	IN FORCE ALL OR PART OF PERIOD	EXPIRED OR CANCELLED DURING PERIOD	IN FORCE AT END OF PERIOD
1	2	3	4	5	6	7

Form 7, Right Hand Page

SUMMARY OF POLICIES & RISKS

AMOUNT OF INSURANCE				
IN FORCE AT BEGINNING OF PERIOD	WRITTEN DURING PERIOD	IN FORCE ALL OR PART OF PERIOD	EXPIRED OR CANCELLED DURING PERIOD	IN FORCE AT END OF PERIOD
8	9	10	11	12

Form 8, Left Hand Page

SUMMARY OF RECEIPTS & DISBURSEMENTS

PERIOD COVERED		CASH ON HAND AT BEGINNING OF PERIOD	CASH RECEIPTS DURING PERIOD							
FROM	TO		POLICY FEES	INITIAL PREMIUMS	ASSESSMENTS	FEES OTHER THAN POLICY FEES	INTEREST RECEIVED	MONEY BORROWED	ALL OTHER RECEIPTS	TOTAL RECEIPTS
1	2	3	4	5	6	7	8	9	10	11

Form 8, Right Hand Page

SUMMARY OF RECEIPTS & DISBURSEMENTS

TOTAL ON HAND PLUS RECEIPTS	DISBURSEMENTS DURING PERIOD									CASH ON HAND AT END OF PERIOD
	DIRECTORS' PER DIEM & MILEAGE	OFFICERS' SALARIES	AGENTS' OR DIRECTORS' APPLICATION FEES	LOSSES	BORROWED MONEY REPAID	INTEREST PAID	PREMIUMS OR ASSESSMENTS RETURNED	ALL OTHER DISBURSEMENTS	TOTAL DISBURSEMENTS	
12	13	14	15	16	17	18	19	20	21	22

An annual summary is derived from the four quarterly summaries in a manner corresponding to that in which a quarterly summary is derived from the monthly summaries. The annual summary figures may be entered in ink of the same color as used for the quarterly figures, but attention should be called to them by a special ruled line above the horizontal space in which they occur, with a double ruled line below the space.

CONCLUSION.

Over 1,500 farmers' mutual fire insurance companies, or more than three-fourths of the total number of such organizations, are relatively small and local concerns. In these local companies the secretaries, who also act as general managers, almost invariably keep the records of their respective companies without the aid of trained bookkeepers or accountants. Where one man is, at the same time, secretary, general manager, and bookkeeper, the emphasis in his selection is very properly placed upon character, good reputation, and practical knowledge of farm risks, rather than upon technical knowledge of bookkeeping. It is not surprising, therefore, that the forms and plans for keeping records now in use by these companies are frequently deficient. In some cases they fail to furnish the information desired either by the directors of the company or by the State insurance departments, while in other cases they involve much duplication of work and of data without any corresponding benefit. A special need of a large percentage of these companies, therefore, is a system of records which furnishes the necessary information and is at the same time as simple and nontechnical as the nature of the business permits.

The system here suggested, while adaptable to all assessment mutuals, has been prepared with a special view to meeting the needs of the numerous local farmers' mutual fire insurance companies. It is believed to embody the methods of keeping records that experience has shown to be most practicable in making available necessary information without imposing needless work or requiring special technical training.

For the convenience of those interested in the system of records recommended and described in the preceding pages, the Department of Agriculture, through the Office of Farm Management, will supply, free of charge, printer's copy of the various forms here illustrated. In so far as its facilities permit, the Office of Farm Management will also render other assistance, when requested, in connection with the adoption and installation of the system suggested in this bulletin.

PUBLICATIONS OF THE U. S. DEPARTMENT OF AGRICULTURE OF SPECIAL INTEREST TO THOSE CONNECTED WITH LOCAL FARMERS' MUTUAL FIRE INSURANCE COMPANIES.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

The Organization and Management of a Farmers' Mutual Fire Insurance Company. (Department Bulletin 530.)

Prevailing Plans and Practices Among Farmer's Mutual Fire Insurance Companies. (Department Bulletin 786.)

Modern Methods of Protection Against Lightning. (Farmers' Bulletin 842.)

Fire Prevention and Fire Fighting on the Farm. (Farmers' Bulletin 904.)

Farmers' Mutual Fire Insurance. (Separate 697, from Yearbook 1916.)

Suggestions for a State Law Providing for the Organization of Farmers' Mutual Fire Insurance Companies. (Department Circular 77.)

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BULLETIN No. 841

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER May 7, 1920

THE WESTERN GRASS-STEM SAWFLY

By C. N. Ainslie,[1] *Entomological Assistant, Cereal and Forage Insect Investigations*

CONTENTS

INTRODUCTION

The western grass-stem sawfly (*Cephus cinctus* Norton) (fig. 1) is in many ways one of the most interesting and important insects that has attracted the especial attention of economic entomologists in recent years. It is a species native to the United States and has been gradually coming into prominence since the beginning of the present century by reason of the change which the feeding habits of the larvæ have been undergoing subsequent to its discovery. Originally a grass feeder, it is becoming a serious menace to the grain growers of the Northwestern States because of its acquired appetite for small grains, within the stems of which it now subsists.

Such changes of diet are probably occurring everywhere with greater frequency than formerly was deemed possible, especially among the phytophagous insects of the Middle West. When given a

[1] The writer wishes to express his appreciation of the assistance afforded by Messrs. J. C. Crawford, A. B. Gahan, and S. A. Rohwer, of the Bureau of Entomology, in the preparation of this paper, the two former in determining parasitic material reared during the progress of the studies of the sawfly, the latter in making a critical examination of a large series of sawfly individuals reared or collected from various parts of North America, and for furnishing detailed descriptions of *Cephus cinctus* besides a key to the North American species of the genus Cephus. Helpful criticisms from these men have added to the value and accuracy of the paper.

The writer desires also to mention the valuable assistance and cordial cooperation of Mr. Norman Criddle, entomological field officer for Manitoba, Canada; of Mr. A. P. Henderson, of Bottineau, N. Dak., and of the several county agents in the infested areas, who have aided in various ways in the accumulation of information and material.

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chance to feed upon the various cultivated plants grown in bulk by the farmer or gardener, many of these insects gradually desert their native host plants and to a greater or less degree change their habits, including in their fare the more succulent and easily found food.

HISTORY

The existence of the western grass-stem sawfly was first made known in 1890 when Mr. Albert Koebele reared adults from larvæ that were mining in the stems of native grasses growing in the vicinity of Alameda, Calif.[1] During the next year, 1891, the species was described under the name of *Cephus occidentalis* by Messrs. Riley and Marlatt, from a series of individuals reared by Mr. Koebele and also

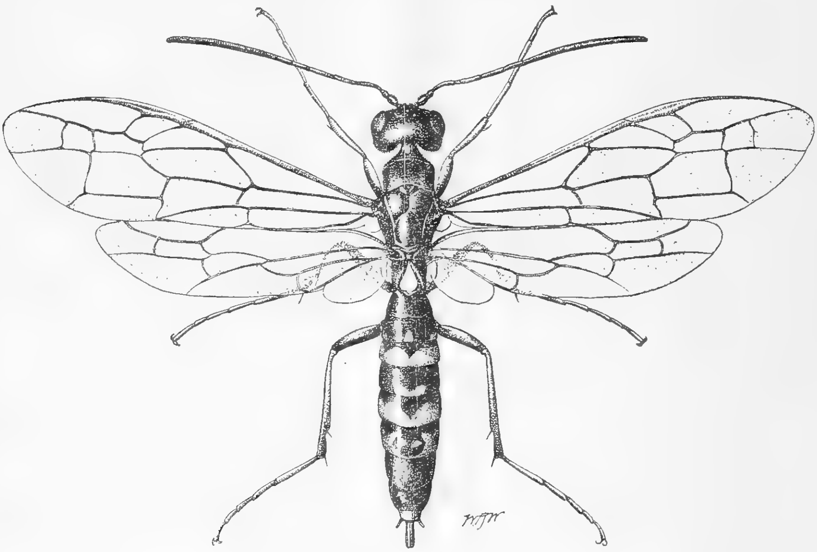

FIG. 1.—Western grass-stem sawfly (*Cephus cinctus*): Adult female. Much enlarged.

from cotypes that had in the meantime been collected in Nevada and Montana.[2] In connection with this description the prophetic suggestion was made that: "The economic importance of this species arises from the fact that it may be expected at any time to abandon its natural food-plant in favor of the small grains, on which it can doubtless successfully develop."

Nothing more was heard of this sawfly until 1895, when the late Dr. James Fletcher, Entomologist to the Dominion of Canada, swept adults at Indian Head, Northwest Territories, on July 5. He believed it to belong to the European species, *Cephus pygmaeus* L., and under

[1] Koebele, A. Notes. *In* U. S. Dept. Agr. Div. Ent. Insect Life, v. 3, p. 71, 1890.

[2] Riley, C. V., and Marlatt, C. L. Wheat and Grass Saw-Flies. *In* U. S. Dept. Agr. Div. Ent. Insect Life, v. 4, p. 168-179, 1891. (See p. 177-178.)

this name it was mentioned in his report for 1896[1] with the further statement that wheat straws containing Cephus larvæ had been sent in by Mr. John Wenman of Souris, Manitoba, who stated that the injury done by them was very slight. Nevertheless the prophecy of five years before had been fulfilled, since these grass feeders actually had attacked small grain.

In 1902 Dr. Fletcher reported, in a private letter, that he had found the larvæ numerous in grasses in the Northwest. In 1905 and 1906 Mr. G. I. Reeves, an agent of the Bureau of Entomology, noted the work of the larvæ in various grasses, chiefly *Agropyron* sp., in Wyoming and the Dakotas, and in 1906 the same observer found the larvæ attacking wheat sparingly near Kulm, N. Dak.

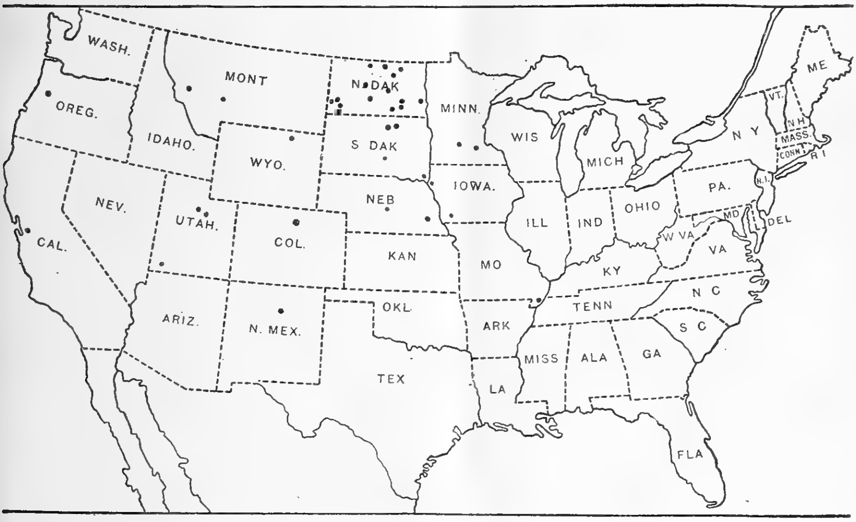

FIG. 2.—Distribution of the western grass-stem sawfly in the United States.

August 31, 1907, Mr. E. O. G. Kelly, then an agent of this bureau, noted a few wheat straws near Minot, N. Dak., that had been burrowed by the larvæ of Cephus.

In 1908 Messrs. F. M. Webster and G. I. Reeves found the larvæ of Cephus working in grasses in the Willamette Valley in Oregon. In the same year Dr. Fletcher again called attention to this insect, stating that in the previous autumn it had appeared in central Manitoba and in the southeastern part of Saskatchewan in much more serious numbers than ever before, and that the quantity of broken straws in the fields was causing the farmers some alarm. Mr. Norman Criddle of Aweme, Manitoba, a close observer and practical farmer, wrote to Dr. Fletcher that this fly had increased considerably during the last year or two, and was turning its attention to wheat and rye.

[1] Fletcher, J. Report of the Entomologist and Botanist, 1896. Can. Dept. Agr. Exp. Farm, 1897. (See p. 229-230)

August 20, 1909, Prof. H. B. Penhallow reported from Sherwood, N. Dak., that he had examined about a hundred fields from Minot, N. Dak., north to the boundary line and several miles into Canada and had found larvæ present in every field but one. He estimated the damage in these fields as ranging from 5 to 25 per cent of the crop, but spoke of one field about 27 miles east of Sherwood where the damage was said to have exceeded 66 per cent. R. W. Sharpe reported similar damage in the Red River Valley, near Fargo, N. Dak.

During 1911 and 1912 the writer found the species occurring freely in the native grasses in various parts of Utah, and as occasion offered

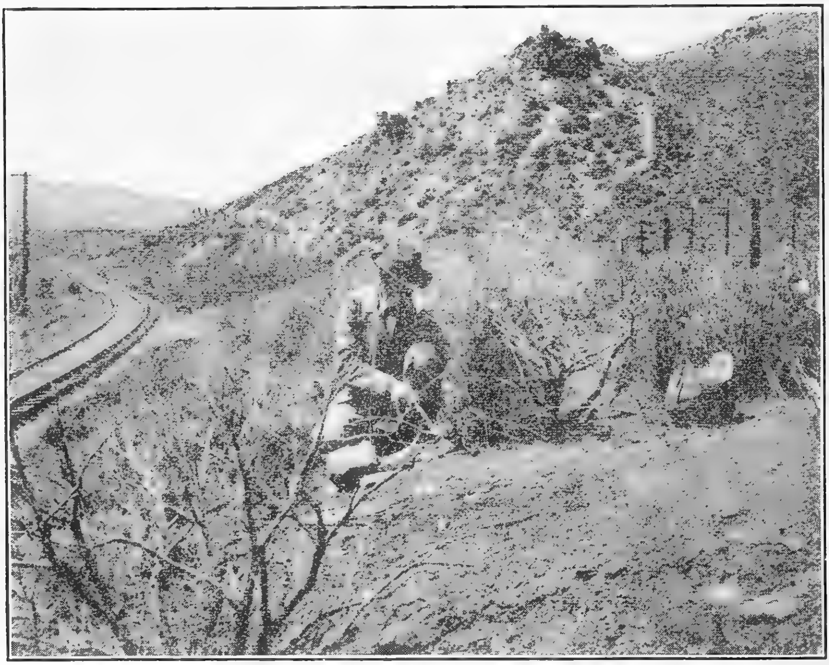

FIG. 3.—Plants of *Elymus condensatus* growing along the railroad right of way. The natural habitat of the western grass-stem sawfly in Utah.

the life history of Cephus was learned. Most of the facts in this paper are the result of this study. (Fig. 3.)

During the years 1913, 1914, and 1915 the writer has found this sawfly almost universally distributed over the Dakotas, Minnesota, Iowa, and Nebraska, feeding in Elymus, timothy, and Agropyron at Elk Point, S. Dak., in *Agropyron tenerum* near Chamberlain, S. Dak., in timothy at Edgeley, N. Dak., in *Bromus inermis* near Merricourt, N. Dak., in *Elymus canadensis* at Shakopee, Minn., in practically all these grasses near Sioux City, Iowa, and in wheat, timothy, and Elymus near Minot, N. Dak. It seems to have little choice in the various native grasses and is ready to attack any of the cultivated sorts provided the stem is sufficiently large for the larval gallery. As a rule, the larger, more robust stems are chosen for attack, especially in cultivated grasses such as timothy and Bromus. Blue grass and similar slender-stemmed species appear to be immune. It is a little surprising that a minute examination of *Stipa viridula* from New Mexico developed the fact that none of the stems of this robust grass were infested. This Stipa was gathered in northern New Mexico, growing in almost the same latitude as the *Elymus condensatus* near Pinto, Utah, where the fly abounds.

August 25, 1916, the writer, then at Pierre, S. Dak., received instructions from the Bureau of Entomology to visit Bottineau County

FIG. 4.—Wheat field of Thomas Yeam, near Souris, N. Dak., showing heavy damage done by the western grass-stem sawfly in 1916.

in North Dakota and investigate injury to wheat. It was believed locally that the Hessian fly was responsible for the damage that was being done. A very superficial examination of the injured fields proved beyond a doubt that the Cephus was present in large numbers and was doing an immense amount of mischief. Every field was infested, not only in Bottineau County, but in the adjoining counties of Benson, Pierce, McHenry, and Rolette. Near Souris, a few miles south of the Canada line, a large field of wheat on the farm of Thomas Yeam was fairly carpeted with the "straw-fallen" grain. (See figs. 4 and 5.) The loss from Cephus injury in this field was estimated at 60 per cent or more. Six feet of drill row here were taken at random and examined plant by plant. Forty-eight infested stubs were found.

an average of eight to each foot of drill row. This would mean 150 to the square yard or about 726,000 larvæ to the acre. Higher counts were made later in this same field, so the average may be larger than stated. During April, 1917, Mr. Yeam's field was again visited and a random square yard marked out and counted. Two hundred and sixty-nine infested stubs were taken from this yard, which would mean more than 1,300,000 larvæ to the acre. Fifty of these stubs were opened and 47 of the imprisoned larvæ that had spent the winter within the straw were found to be normal and very much alive. The proportion of living individuals among the hibernating larvæ seldom falls below this ratio.

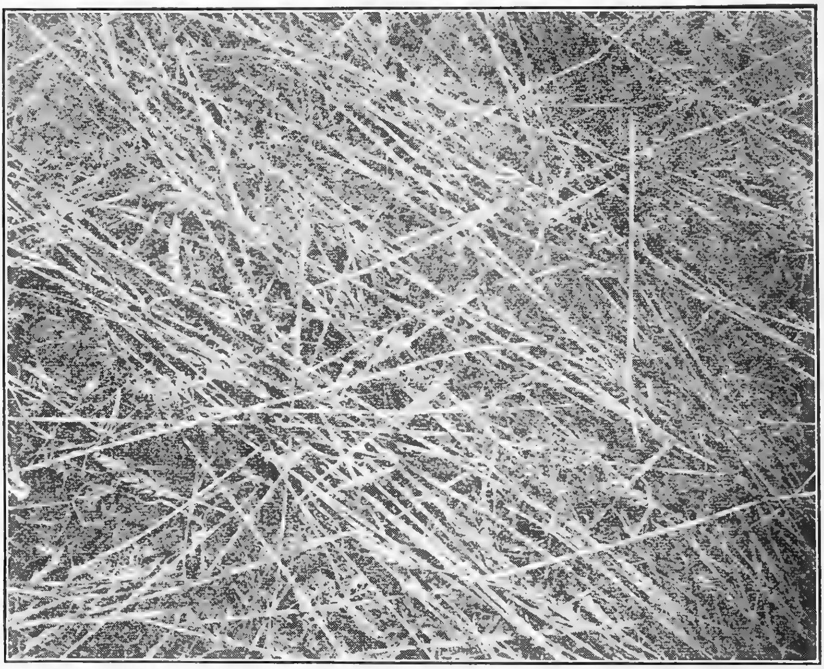

FIG. 5.—Bird's-eye view of wheat in Thomas Yeam's field, Souris, N. Dak. Ninety per cent of these fallen wheat stems have been mined by the western grass-stem sawfly.

The spring of 1917 witnessed a peculiar condition of things in Bottineau and the adjoining counties of North Dakota. The dry weather hindered the growth of both grasses and grains, so that when the adult Cephus began to appear in June there was almost no opportunity for oviposition. Stems of Bromus from chance sods growing among wheat and on waste ground were filled with eggs. Young plants of spring wheat that had barely begun to joint were attacked and often contained as many as three and four eggs placed in the stem close to the ground. With a few strokes of the net 136 adults were swept from young wheat, so numerous were the flies at that time. In spite of the unfavorable oviposition conditions of that spring, the eggs appear to have hatched and at harvest time the majority of the wheat stems had been bored and many were cut off at the base. Careful harvesting and the use of horse rakes saved a large proportion of what otherwise would have been a total loss. The infestation was much more general than in 1916.

A somewhat hasty reconnaissance was made through north-central North Dakota in August, 1919, that it might be ascertained as definitely as possible just how the Cephus attack was progressing. A number of fields in Bottineau County were examined and found to be heavily infested. Most of these had been raked after harvest and it was consequently impossible to compute accurately the percentage of infestation. The numerous sawfly-inhabited stubs in the drill rows, however, proved the severity of the attack. It was roughly estimated that about 30 per cent of the grain had gone down in most of these fields as the result of Cephus work. This figure is probably very conservative.

It is conceded by many observers in that region that the injury during the year 1919 was greater than during any previous year since the study of this pest was begun. More fields had been seriously invaded and were injured to a larger extent than had before been observed. Even fields of durum wheat, hitherto believed to be nearly free from fly attack, were severely injured in 1919, if the statements of reliable farmers are to be accepted. The question of immunity of durum wheat will be discussed later in this paper.

It may be stated, however, that the farmers are profiting by past experience and have used horserakes in stubble fields to such an extent that the percentage of actual loss of grain has been reduced to a small figure. The quality of grain from the fallen straw is naturally somewhat below the normal, since the work of the larvæ in the stems produces some injury in the heads as they fill.

Cephus was found mining wheat near Hettinger in southwestern North Dakota, July 18, 1917. September 22, 1917, infested wheat was found near Mott, 30 miles north of Hettinger. In October of the same year many wheat fields in Towner and Cavalier Counties, in northeastern North Dakota, showed heavy infestation, although during the previous year it was difficult to discover more than a trace of Cephus presence in the wheat in this region. None was found in the vicinity of Fargo, although it doubtless occurs throughout the entire Red River valley.

A gathering of sods of *Elymus canadensis* sent to the writer from Charleston, Mo., during the summer of 1917 contained at least one larva of *Cephus cinctus* that had been boring the stem of this grass in that region. This locality is a little south of the latitude of Pinto, Utah, where this insect abounds.

Roughly speaking, so far as is now known, the sawfly inhabits an area bounded on the north by a line far into Canada; on the east by the Mississippi River, or probably a little east of that; on the south by latitude 36°; and by the Pacific Ocean on the west.

From the foregoing brief summary of its history it will be seen that *Cephus cinctus* is distributed over an immense territory and that it constitutes a potential menace to the small grains throughout this vast area. As the acreage of native grasses is decreased from year to year by the bringing of wild lands under the plow, pests such as the sawfly will be forced to depend in an increasingly large measure upon the small grains and other products of the farms. On this account the injury caused by these formerly harmless insects bids fair to increase steadily. In the past the numbers of grass-feeding insects such as the one considered in this paper have been governed mainly by the supply of food plants. A dry summer that retarded the growth of long-stemmed grasses would automatically reduce the numbers of the insects that lived within these grass stems and perhaps bring certain species to the point of extinction. It is easy to see how seasonal fluctuations in vegetation would, to a large extent, either multiply or diminish the numbers of these insects.

Then again, the farmer, by introducing fields of grain into a region previously uncultivated, brings in conditions unknown before and invites the attack of these and other formerly harmless insects, making it possible for them to become a menace to his future. Such a study of life history as has been attempted in this paper is urgently necessary in order that control measures may be undertaken successfully when such insects become pests.

FOOD PLANTS

The various species of Agropyron and Elymus, genera both of which are well represented in the West, appear to have been the original hosts of the larvæ. Since their feeding habits have been modified by changing agricultural conditions, the list of their present host plants, so far as known, stands as follows:

Elymus canadensis	*Agropyron occidentale*	*Calamagrostis* spp.
Elymus condensatus	*Agropyron caninum*	*Festuca* sp.
Agropyron tenerum	*Hordeum jubatum*	Wheat
Agropyron richardsoni	*Bromus inermis*	Durum
Agropyron smithii	*Phleum pratense*	Spelt
Agropyron repens	*Deschapsia* sp.	Rye

Barley probably should be added to this list.

Since the larva is wholly unable to move from one stem to another, it is very obvious that the host stem must be large enough to afford both shelter and food during its entire growing period. Hence only the larger-stemmed grasses can be mined successfully by the Cephus larvæ. Occasionally an unusually vigorous plant of a slender-stemmed grass, like *Hordeum jubatum,* affords stalks with diameter sufficiently great to be attacked by Cephus.

Small grains, such as wheat and rye, readily serve as hosts to this insect, because they are of suitable size and the length of their growing season coincides with the growth of the larva. Even if harvest time should happen to come before the maturity of the larva, the reaping machine probably would sever the stem far enough above ground to leave the larva below the sickle cut, where it could house itself safely before the end of the season.

Judging the future by the recent past, it seems probable that this fly, before another decade is past, will be found attacking practically all of our native and cultivated grasses and most of our grains.

It must be remarked in this connection that up to the present time this species has confined itself entirely to the West and has been found in only a few localities east of the Mississippi River. Its choice of wheat for food has taken place, so far as known, only in North Dakota and western Canada, although it is probable that Montana wheat fields have been invaded. From present appearances its attacks probably will be confined to vegetation growing within the area where spring wheat is sown.

THE EGG

The egg of *Cephus cinctus* is, when newly laid, decidedly crescent-shaped, glassy in appearance, milky-white in color, usually quite symmetrical, the ends of the crescent tapering and rounded. It is marked by very faint, short, longitudinal lines or wrinkles, placed without regard to order or pattern.

The size of the egg varies with the size of the female that produced it and measures from 1 mm. to 1.25 mm. in length. The greatest breadth is about one-third the length.

The covering membrane is hyaline and transparent. Although very thin and delicate it is sufficiently strong so that the egg may be safely lifted and moved by the aid of a fine brush. The egg always lies free within the stem of the host plant, either in the stem cavity or in a hollow excavated by the ovipositor of the female that placed it. This cell is always a little larger than the egg, so that it is comparatively an easy matter to remove the egg to a moist cell or elsewhere for study.

The number of eggs distributed by each female appears to vary but little. Dissections of a number of adults taken in the field and of others reared in captivity agree in most cases in giving a count of about 50 eggs in the ovaries, these eggs being, as a rule, equal in size and apparent maturity.

DEVELOPMENT OF THE EGG

After a number of trials it was found to be impracticable to rear the egg *in situ*, since it was next to impossible to maintain the proper moisture conditions within the stem. The method that finally was adopted, and that gave excellent results, was to remove the egg from the stem and place it in a minute drop of water within a small thin watch glass which was then immediately inverted on a glass slip and sealed with a ring of water to prevent undue evaporation. This form of moist cell proved quite satisfactory and permitted continuous examination of the egg with a moderately high-power lens during the entire period of incubation. It was found necessary, in order to continue the requisite moisture supply during a period of several days, to invert over the sealed cell a larger watch glass and over this in turn a tumbler. In this manner evaporation was reduced to a minimum. It is altogether probable that the amount of moisture in such a protected cell exceeded that normally present within the grass stem, but in every egg treated in this way the incubation appeared to proceed naturally.

Temperature and moisture are, without any doubt, the prime factors that hasten or retard the egg development. The temperature maintained within the laboratory during the course of these investigations was much more equable than that in the field, where, as in Utah, the heat of the sun through the daytime, followed by a chilly night, must alternately hasten and check development. The data given below, therefore, may only approximate what actually takes place under field conditions.

A few hours after the egg leaves the oviduct the milky-white contents of the egg which at first completely filled the envelope shrink a little from each end leaving a transparent space or vacuole. Gradually the interior mass of exceedingly minute particles coalesces until about the second day when a series of faintly discernible cells arranging themselves along a central axis begins to appear. Early on the third day the form of the larva can be dimly seen, the head being almost transparent and filling one end of the egg sac. The body is looped on itself, the cauda folded beneath the abdomen and extending forward nearly to the head. By the close of the third day the abdominal segments are usually well defined.

During the fourth day, in most cases, a spasmodic and intermittent heart beat may be noticed. These pulsations become more and more regular as the hours pass and during the fifth and sixth days the heart beats with much regularity at the rate of about 120 impulses per minute. At intervals, for some unknown reason, it may slow down to 75 beats, but soon resumes its former rate.

The head appears abnormally large at this time, but although its general outlines are well defined the brown jaws and eye spots are not yet visible. Over night, at the close of the fifth day, the jaws turn brown and the eye spots appear and darken. Usually, after the fourth day, the muscular system of the larva is in almost constant motion, shifting and adjusting, with the heart pulsating and the muscles moving, all clearly to be seen through the transparent membrane that serves as the shell.

The activity of the larva within the sac increases during the sixth day, and either on this day or the seventh it escapes from its confinement by a series of convulsive movements that rupture the delicate shell and set it free.

After the first day the egg changes shape, becomes intumescent, generally loses its crescentic shape entirely, and grows oval or reniform in outline.

THE LARVA

When it escapes from the egg the larva (fig. 6) possesses a very large head armed with a pair of powerful biting jaws, a weak, slender body, and a most vigorous appetite. It is very active from the start and begins almost at once to feed upon the living parenchymatous tissue by which it is surrounded in the interior of the stem, excavating for itself a threadlike gallery both above and below the spot where the egg formerly lay. The larva is at first nearly transparent and colorless until it becomes filled with the tissue on which it exists.

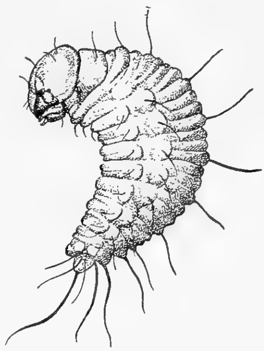

FIG. 6.—Western grass-stem sawfly: Newly-hatched larva. Greatly enlarged.

The body segments are strongly and clearly marked from the time the larva leaves the egg. The jaws are brown, three or four pointed, the points chisel-shaped, beveled on the inside edge. The brown face plate is filled with crossed bands of striated muscular fiber that actuate the powerful jaws which form the most important item of the domestic economy of the young Cephus. The caudal horn, by means of which the larva moves up and down in its gallery, is also brown and is armed, even in the first instar, with a series of stout bristles at the base of its cylindrical and squarely truncate extremity. The larva is footless, the position of the legs being marked by minute, rounded tubercles terminating in a few short bristles.

Although the primary excavation made by the larva may extend for a short distance above the egg cell, the general course of the progress is invariably downward. In its earlier stages of existence, at least, the larva traverses its gallery several times, swallowing repeatedly the same fragments of tissue that have already been devoured during the first excavation of the stem. Young larvæ are frequently found several inches above the lower end of the boring, moving through the solidly packed "sawdust." As the larva approaches maturity it is doubtful if it ventures into the upper and slender part of the stem, but it still reworks the frass farther down, enlarging the bore in places.

The number of instars is difficult to determine, owing to the larval practice, just referred to, of passing all the frass several times through the digestive apparatus. Nearly all the cast skins disappear completely under this treatment, only the heavily chitinized parts such as the jaws and caudal horn being recognizable in the burrow. Care-

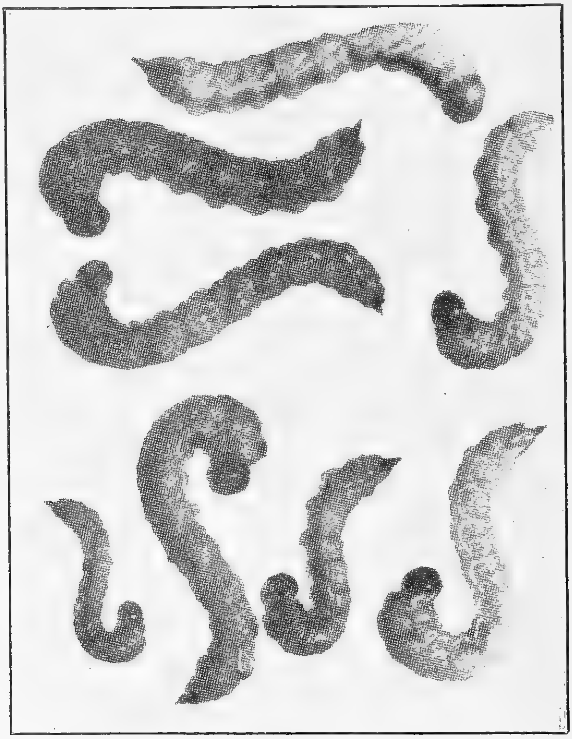

FIG. 7.—Western grass-stem sawfly: Mature larvæ removed from their galleries. Enlarged 4 diameters.

ful investigation of these fragmentary remains appears to establish the fact that there are four molts. The contents of innumerable stems have been examined with scrupulous care and with varying results. In a few cases as many as four sets of jaws and in others four caudal horns have been found, mixed with the frass within the stems. Seldom were more than four sets removed from a single stem; usually only three were found. As is stated elsewhere in this paper, it is no uncommon thing to discover two and even three larvæ mining a single stem, although but a single individual can possibly reach maturity with the amount of nutriment contained in one stem. It is believed that the larva that finally reaches maturity has devoured its rivals. It is obvious that the remains of these superfluous individuals would naturally be counted when a census of exuviæ was undertaken and would complicate the result. But from the best evidence obtainable it is almost certain that there are five instars in the larval life of this species.

The length of the larval period is probably about 60 days, varying more or less with the warmth of the summer and the state of maturity of the host stems. The acceleration or retardation of the oviposition period owing to an early or late spring has much to do with the date of maturity of the larvæ, and possibly with the length of the larval period. August 29, 1911, at Kimballs, Utah, at an elevation of 7,000 feet, the writer found mature larvæ in stems of *Elymus condensatus*. The next year, at the same place, oviposition was beginning freely during the first week of July. The determination of the larval period is wholly inferential, based upon the findings in a series of stems (figs. 7 and 8).

Fig. 8.—Western grass-stem sawfly: Mature larva. Enlarged 5 diameters.

The full-grown larvæ vary greatly in size, their growth being governed, as is usual in the case of such borers, by the quality and quantity of food consumed. Those living in wheat stems are much smaller as a rule than those found in rank-growing grasses such as Elymus. Measurements of a series of individuals give variations of from 8 to 14 mm. in length and from 1 to 2 mm. in diameter.

When mature the larva always seeks the extreme base of the stem, where it soon begins its preparations for hibernation. Its first move is to cut a neat V-shaped groove entirely around and inside the stem, usually at or a little above ground level. This groove never severs the stem completely, but so weakens it that the upper stalk, swayed by the wind, will break off completely when dry, leaving a stub that is very characteristic of the work of this insect (fig. 5). In this simple manner the larva provides for the easy escape of the adult in the following summer. The length of the stub thus formed varies greatly. In *Elymus condensatus* the stub sometimes will project above the ground as much as 3 or 4 inches, while in other grasses, and especially in wheat, stubs easily can be found less than an inch in length in all.

Instances have been observed where two or more grooves had been cut inside the same stem, as if the larva had been uncertain as to the best place for severing the grass. After cutting its characteristic groove within the stem the larva forces a mass of the débris into the bore just below the groove and in this manner plugs the upper end of the stub that is to be left in the ground after the upper stalk has been broken away (figs. 9, 10, and 11). This dry frass in some manner is packed firmly into its place, perhaps by means of pressure rather than by being cemented with a liquid furnished by the larva, since the plug is readily penetrated by moisture. This is somewhat remarkable in view of the fact that an undue amount of moisture appears to have a disastrous effect upon the mature larva. One would suppose that these stubs, often wholly submerged in water-soaked earth for weeks at a time, would absorb, during the long period of hibernation, a fatal amount of dampness from the rain or melting snow. But there is no evidence that this ever happens.

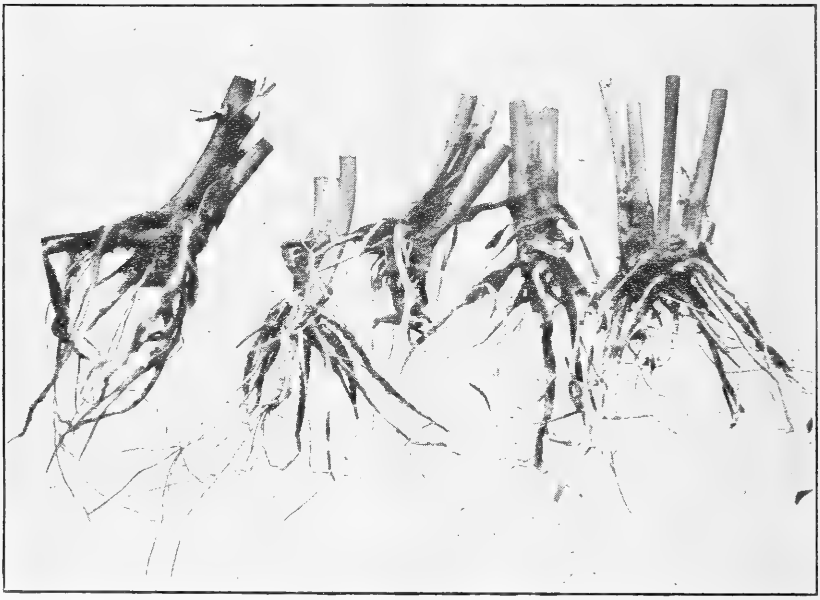

FIG. 9.—Western grass-stem sawfly: Infested wheat stubs from Bottineau County, N. Dak.

September 16, 1911, one of the larvæ was removed from the hibernation chamber and placed in a small vial, still inclosed within the silken tube or cocoon, which was unbroken. For months this larva remained passive and motionless except when the vial was exposed to bright sunshine. Because of the light or heat, or both, when placed in the sunlight it would become active at once, and travel up and down within its cocoon in its efforts to escape. January 20, 1912, to prevent the air in the vial from becoming too dry a small drop of water was introduced and the vial again corked tightly. An hour later it was noticed that the silk tube had collapsed and the larva within was limp and apparently dying. The surplus moisture was removed quickly, whereupon the larva revived almost at once.

If the same amount of moisture had entered the stem where the larva was hibernating it probably would have caused its death. This experiment, taken in connection with others that were not so directly conclusive, seems to prove that the porous plug in the stub must prevent in some way the admission of an undue amount of moisture into the chamber below, although water readily penetrates it.

The gallery below the plug is always entirely free from débris, forming a hibernation chamber and later a pupation cell. Within this chamber the larva lies with its head up and usually pressed against the barrier at the top, always on the alert to retreat downward at any sign of disturbance. It descends by alternately flexing and straightening the body, bracing itself first by the jaws, then by the caudal horn as it hitches its way down In ascending, the caudal horn is thrust against the side of the gallery or the cocoon, the body is straightened, the jaws obtain a purchase to hold the distance gained, when the body is again drawn up until the caudal horn is applied to the side wall for another push.

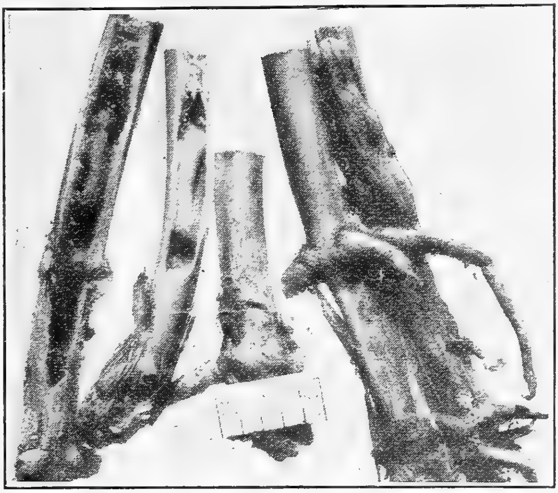

FIG. 10.—Western grass-stem sawfly: Infested wheat stubs, enlarged 3 diameters, the two left-hand ones opened to show hibernating larvæ *in situ*.

Late in the summer or during the autumn the larva spins for itself within the hibernation chamber an almost transparent tube of filmy silken tissue. This silk tube is sometimes several times the length of the larva, is closed at both ends, and is free from the sides of the chamber, so that often it can be readily withdrawn entire. When first constructed this fabric is comparatively strong and pliant but after some months it grows more brittle and is easily ruptured. As a rule it remains intact until the emergence of the adult. Even the presence of half a score of parasitic larvæ often fails to wreck the delicate structure during the winter.

The longevity of the sawfly larvæ is remarkable and is worthy of mention. September 8, 1911, a number of stubs of *Elymus condensatus* containing Cephus larvæ were gathered and set upright in sand within doors. From time to time this sand was moistened but finally was allowed to stand perfectly dry. During October, 1912, these stubs were examined and a number of the inclosed larvæ were found to be still living, active, and unchanged. Four months later, 17 months from the time they were gathered, they were still alive and feebly active. Infested stubs of the same grass taken during September, 1912, and treated in the same manner, contained at least one living larva on February 23, 1916, 3 years and 5 months later. The others had nearly all died within about 30 months of the time they were gathered. It is possible that the lack of necessary moisture may account for the retardation of these captives. However, the same retardation of development has been noted in the field. Inhabited stubs of the previous year's growth of grass and grain not infrequently have been found, containing larvæ that were to all appearances entirely normal and active. It appears more than probable that in this manner the perpetuation of the species is assured in case of unfavorable seasons.

Fig. 11.—Stems of wheat grooved internally by larvæ of the western grass-stem sawfly.

During the winter the larvæ are, of course, frozen, or are chilled into immobility and show no signs of life when disturbed. As soon as the earth warms in the spring they again grow active and move freely up and down within the limits of the silk-lined hibernation chamber until the time of pupation arrives.

THE PUPA

The pupa when first formed is milk-white, slender, and somewhat longer than the larva from which it was derived. Its average length is not far from 12 mm. and its breadth is about 1.5 mm. At first the pupa lies motionless within the silken pupation chamber or cocoon (fig. 12) for probably a day or two, after which inactivity it again becomes animated. When disturbed it will endeavor to escape the threatened danger by moving either up or down the tube, hitching itself along in much the same manner as the larva but going a lesser distance with each effort. Like the larva it is almost always found with its head pressed closely against the plug of frass at the upper end of the chamber. In a few cases pupæ have been discovered heading downward in the stem. It is doubtful if these can reverse their position, but the adults which issue are probably agile enough to turn about and escape.

The duration of the pupal period is not known certainly, but is believed to be very brief, not more than a week at the most. After the first day the legs and body darken until they become a lustrous black within the transparent, almost invisible filmy membrane in which they are inclosed. This membrane is often lacking and may occasionally be destroyed by the movements of the pupa within the chamber.

When fully mature the pupa changes within the cell to an active adult. This adult remains imprisoned until some unknown impulse compels it to force its way upward through the plug of frass placed at the upper end of the chamber by the larva 9 months before. The writer, by splitting stubs of grass or grain in June, has liberated adults repeatedly, which, when free, were able to take instantly to wing without any preliminary process of drying or other preparation. These adults were evidently resting, in perfect condition, waiting for some secret signal from the outside world before taking the final step for liberation.

A very few die within the cell, possibly because of lack of vitality needed to break through the stopper of frass above them. In cases where the girdling of the stem was inefficiently done, so that the grass stalk did not break off during the winter season, the adult dies as a matter of course, since these flies apparently are not fitted with jaws capable of biting through the woody stems of dry grass.

FIG. 12.—Western grass-stem sawfly: Pupa. Three and one-half times natural size.

THE ADULT

The adult *Cephus cinctus* is a beautiful insect with a polished black body marked by three prominent yellow bands across the abdomen. The legs are yellow and the wings smoke-colored.

The description, by S. A. Rohwer, follows:

Length 7 to 12 mm. Head shining, polished; anterior margin of clypeus truncate with angles prominent and sometimes slightly denticulate; antennæ usual for the genus; thorax shining but with setigerous punctures on scutum; sheath nearly parallel-sided but a little broader at base, apex truncate with corners rounded; hypopygidium rather narrowly subtruncate apically. Black marked with bright lemon yellow, amount and extent of yellow markings varying greatly; head of female usually black but more rarely with face entirely yellow or having yellow spots; head of male black but always with yellow on face; thorax black, the upper angle of mesepisternum, parapteron, and scutellum (usually) yellow; legs yellow with coxæ, trochanters (occasionally both of these having yellow marks), bases of femora more or less, apices of tibiæ and tarsi sometimes, black; hind tibiæ and tarsi sometimes reddish yellow; abdomen black, spot or band on second tergite, band on third, fifth, sixth, and eighth tergites and lateral margins of tergites yellow, the size and extent of these markings varying and occasionally the fourth tergite having a yellow band; wings fuliginous, venation dark brown, costa and stigma yellow.

The female is noticeably larger than the male, and in the field is captured much more easily.

The characteristic attitude of the adults of either sex while at rest is to lie flat against the grass stem, head downward, the body closely appressed to the stem, the legs not spread but stretched in line with the body while the body itself is concealed behind the closely folded, smoke-colored wings. The ease with which such a strikingly colored fly, while in this position, can escape observation, is remarkable. During the chill of the morning and after sundown this attitude is universally assumed. When basking in the sun at midday, on the warm side of a grass stem, the fly is much less compact, with the wings partly spread and the legs outstretched in order to absorb the utmost of the warmth. Like most Hymenoptera, this species is very partial to sunshine and rarely is seen abroad on a cloudy day. In fact, in cloudy weather it is not easy to find these flies at all, unless one is entirely familiar with their habits.

They are weak fliers and seldom travel to any great distance at one time. In Utah they commonly move about among the plants of bunch grass, making short flights from tuft to tuft. If the wind rises or the sun goes behind a cloud they promptly disappear until conditions again become satisfactory. The writer has never taken the adults at any great distance from their breeding places.

Their hovering flight is peculiar, the swaying motion of their bodies in the air reminding one of certain tipulid flies during their mating air dance. They often hover for a long time to the windward of a grass plant without alighting, seeming to enjoy the motion. The males are on the wing much more than the females, but neither sex will remain in the air while the wind is strong or when it is cool. The adults are not at all timid and can often be readily taken from the grass stems with the fingers. When conditions are favorable for her the female is usually too intent on oviposition to be easily annoyed but if disturbed beyond endurance she quickly disappears, her dark color and slender body enabling her to vanish completely among the vegetation.

Copulation is very brief, usually lasting less than a minute. No notes were made on the attitude assumed during the operation.

The species is single brooded, the adults appearing during the spring and going out of existence some time about midsummer.

The earliest individual met in Utah was taken in a net April 26, 1910, in an alfalfa field. Adults have been seen in the mountains late in July and they probably linger longer than that, ovipositing in such green grass stems as they can find. Near Kimballs, in Utah, September 8, 1911, the writer took very young larvæ from stems of

Elymus condensatus, growing from plants that had been browsed by cattle and had thrown up fresh green stalks.

Mr. Norman Criddle states that in Canada the adults appear during the second week in June and may be met with until about July 10. Occasionally they may be found feeding on flowers. Doctor Fletcher has taken them in Canada on flowers of the tumbling mustard. It is unquestionably true that the time of their appearance and the length of adult life are both largely governed by climatic influences and vary with the season.

When confined in emergence tubes or other limited places the males develop savage instincts and attack each other without mercy, using their jaws freely to snip off the antennæ, and, in some cases, the legs of their rivals. Singularly, very few of the females confined with them are thus mutilated.

OVIPOSITION

Weather conditions have always been an important factor in controlling the oviposition of very many of the Hymenoptera, and they are of particular importance in the case of the Cephus. These flies go into hiding when the day is dark, damp, cool, or windy. Only on bright, warm, still days are they to be found busy with the operation of placing their eggs. In Utah, where the first studies of their habits were made, the mornings and evenings are chilly as a rule, hence the activity of these flies is confined to the hours near midday. They are everywhere the most active between the hours of 10 a. m. and 2 p. m.

The swaying of the grass and grain stems in the wind appears to be a hindrance to them in alighting and ovipositing. A gentle breeze will often keep them hovering for several minutes to the windward of their goal, while a sudden mountain gust is apt to put an abrupt end to all efforts for the balance of the day. Their actions are controlled by unknown factors, for sometimes on a still, sunny day they will spend much of the time roosting on the stems, while again, under apparently the same conditions, they are constantly in motion, flying and hovering a long time before alighting.

While the female is poised in the air before a sod of grass or grain she is evidently busy selecting the particular stem in which she hopes to oviposit. Once she has chosen and settled, she seldom changes to another stalk, although she may halt at several places on a single stem and attempt oviposition at each pause. Occasionally, after a hasty examination, she may again take to wing and make another choice. Repeated observations seem to have established the fact that one of the chief requisites of a proper stem is that it shall not yet have put forth a head. In all the countless instances where oviposition has been observed, the female has never been known to choose a stem with a head.

When she has made her selection of a suitable stem, the female usually alights about half way up and runs briskly to the upper end, halting almost imperceptibly every few steps. The gait of an ascending fly is so characteristic that it determines with much certainty if the individual is a female intent on oviposition.

Fig. 13.—Western grass-stem sawfly: Female ovipositing. About life size.

Arriving at the apex of the stem, after a careful survey of its condition, she frequently makes an elaborate toilet, preening herself most carefully, until she is in perfect condition. She then descends, exaggerating slightly the hesitating step by which she had ascended. The antennæ are held horizontally in front of the head as she moves, and she occasionally touches the surface of the stem with their tips. There is none of the rapid antennal vibration so common among the smaller chalcids and many other Hymenoptera. She gives no evidence of being in search of any particular point, but goes straight down the stem. When satisfied that she has gone far enough she halts abruptly, usually an inch or less above the second node from the top of the stem, slowly arches her abdomen and clasping her hind pair of feet around the stem as far as they will reach begins to drive the saws into the hard outer tissue. Figure 13 shows the attitude taken at this time. These saws are exquisitely fashioned, curved like a scimitar, double, very thin with serrated edges. (See fig. 14.) They are used to split the outer coating of the stem rather than to cut it, and they make an opening so exceedingly small that it is almost impossible to find the scar after the wound has healed. These saws are gradually forced into the stem, the operation occupying a minute or more. In the field the female always heads downward during oviposition and the curve of the saw blades brings them, when fully inserted, in a line parallel to the axis of the stem. They are frequently partly withdrawn and their direction slightly changed. When the stem is in proper condition the saws are thrust in several times, as far as they will go, then are withdrawn,

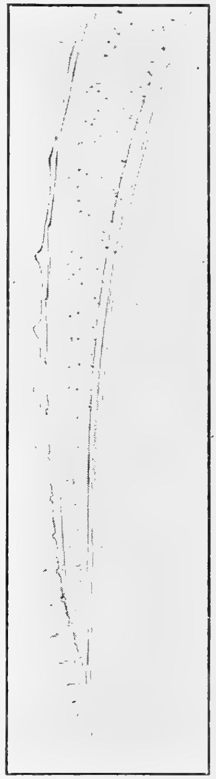

Fig. 14.—Western grass-stem sawfly: Saws, greatly enlarged.

the dorsal part of the pygidium being used as a fulcrum to extract them. They are inserted again, this time often with a twisting motion as if trying to enlarge the opening. They are finally forced in as far as possible, as is evidenced by the tenseness of the rear legs straining at the stem, and are held in this position for half a minute or more. This is probably when the egg is deposited, the insect standing practically motionless except for a slight vibration of the antennæ.

A laboratory note may be of interest, giving in detail some of the facts that have been mentioned above:

June 5, 1912. The adult Cephus were emerging freely from the Elymus material brought from the mountains, and it occurred to me it might be possible to secure some views with the camera if they could be induced to oviposit. Several females were observed attempting oviposition in the dry stems from which they had recently emerged.

A green stem of Elymus was planted in a tumbler of wet sand and the camera focussed on this stem about midway. After a few trials I discovered that this stem must be short and headless.

The females were taken from the cage and placed, one at a time, on the damp sand in the tumbler. Their first act in every case was to spend a long while drinking eagerly of the water held in suspension by the sand. A few of them sipped water for as much as half an hour before they could be induced to leave. When guided to the base of the Elymus stem they would usually ascend without a moment's hesitation. Once started they would go to the very top and there would either preen themselves interminably, or would wheel and descend with the usual cautious, hesitating gait, a few steps at a time. When part way down, without apparently choosing any especially suitable spot, the abdomen would arch and oviposition would begin. Sometimes these efforts were plainly failures, but some of the flies would sink their saws well into the tissue of the stem and stand for a number of seconds motionless, thus affording an opportunity for the camera.

Much time was lost to-day because of the exasperating neatness of these insects. Each one would brush herself over and over again with the most minute exactness and no amount of urging would avail to shorten the process. The same careful preening has been frequently observed also in the field.

Several life-size views of these flies were obtained to-day by the above method, views that would be impossible in the field because of the almost constant motion of the limber grass stems. Several of the females became confused to-day when compelled to remain on a certain part of the grass stem during oviposition, and faced up the stem instead of down as they invariably do, normally.

When busy with oviposition they seem oblivious to whatever is going on around them, and the writer has repeatedly watched, through a half-inch triplet, the female manipulating her saws. Close observation did not annoy her in the least when the lens was carefully handled, and she paid no attention to the proximity of the onlooker. Under the closest scrutiny it is impossible to determine just when the egg is passed into the stem. It is probably at the time when the female stands motionless after the saws have been driven in to their full length.

The function of these saws appears to be twofold. At Pinto, Utah, in June, 1912, the writer found that the eggs were invariably placed in a cell hollowed in the solid parenchyma of the stem of *Elymus condensatus*, this cell being a little larger than the egg. Besides piercing the stem, the saws are also of use in excavating this egg cell, in case such a cell is needed. At Kimballs near Salt Lake City, in the same grass, the eggs were nearly always placed in the hollow part of the stem, lying free in the central cavity.

Normally but one egg is placed in each stem. However, no attention is paid to previous oviposition and as many as five eggs have been taken from a single stem. As is stated elsewhere, only one of these larvæ can possibly survive until fall, so this multiplication of eggs simply means economic waste for the Cephus.

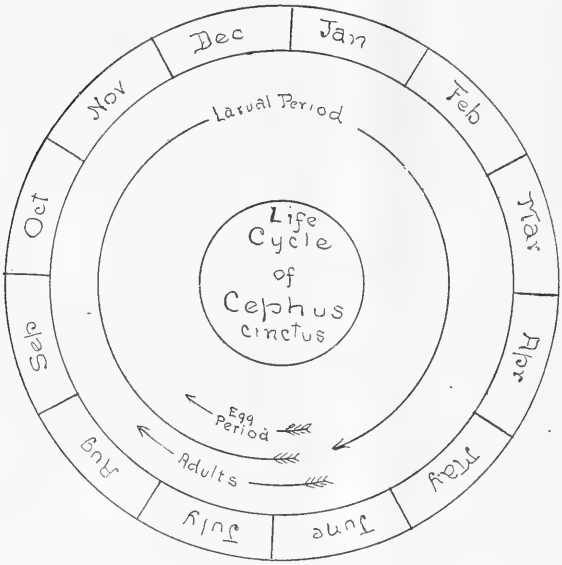

FIG. 15.—Life-history diagram of the western grass-stem sawfly.

The date of oviposition varies with the latitude and the altitude. At Pinto, Utah, on the edge of the desert country and with a low altitude, newly hatched larvæ were found June 14, 1912, while at Kimballs, 350 miles north of Pinto and with an altitude of 7,000 feet, oviposition was beginning during the first week of July in the same year.

Mr. Criddle states that in Canada most of the eggs are deposited during June. The date of oviposition in the Dakotas and in Minnesota is unknown. (Fig. 15.)

KEY TO THE NORTH AMERICAN SPECIES OF CEPHUS

Through the courtesy of Mr. S. A. Rohwer of the Bureau of Entomology a key for the determination of the known species of the genus Cephus occurring in North America is here presented.

Stigma and costa dark brown of a uniform color; mesepisternum black; femora black; apical tergite and venter black; face and scutellum black (face of male with yellow spots) . . . . *pygmaeus* Linnaeus.

Stigma in greater part and costa yellow; mesepisternum with the upper angle yellow; apical tergite and usually the venter in part yellow; femora usually mostly yellow; face and scutellum of female usually black but occasionally with yellow spots . . . . *cinctus* Norton.

NATURAL CONTROL

In the usual scheme of things an undue increase of insect pests is controlled naturally by parasites that take a heavy toll of their hosts and prevent their multiplication. Under normal conditions, when the *Cephus cinctus* existed wholly in grass stems, the larvæ were attacked with varying success by two or more species of parasites that destroyed numbers of them and kept them within reasonable bounds. Since the fly has begun to change its habits and to subsist on wheat and other small grains to a certain extent, these parasites apparently have not yet learned of the change and are confining their attacks, as heretofore, almost entirely to those larvæ that they find in grass stems. A very few parasites have been taken from infested wheat stubble, and there is little question but that in course of time the busy little parasites will hunt their prey in the grain stems and do their share in helping to control this pest.

FIG. 16.—Larvæ of *Pleurotropis utahensis*, a parasite of the western grass-stem sawfly, *in situ*.

The most common parasite found everywhere in the grasses is *Pleurotropis utahensis* Cwfd., a beautiful little bronze-green chalcid that was reared by the writer from numerous larvæ taken near Salt Lake City, Utah, from Cephus hibernation cells. This species appears to kill the larva only after it has formed its hibernation cell. It is gregarious and seldom or never attacks its host singly. As many as 12 of its larvæ have been taken from a single cell, but 5 or 6 is a more common number. These larvæ are white and measure from 2.5 mm. to 3.5 mm. in length. They are somewhat active and travel slowly about the cell when mature. They are often found crowded together in one end of the cell, but when disturbed will scatter about the chamber (fig. 16).

Although this species is widely distributed and propagates in numbers it appears to destroy but a small percentage, possibly 10 per cent of the Cephus larvæ in the native grasses of Utah. In Bottineau County, N. Dak., it attacks the sawfly very freely in Bromus and timothy, and in some localities has killed more than 50 per cent of the Cephus larvæ. Indeed, it and one other parasitic species are so numerous in these roadside grasses that it would seem poor policy to recommend the cutting of the grasses in midsummer as a measure of Cephus control. As has been stated, few parasites have been found in stems of wheat, but, without doubt, they will learn very soon of the presence of Cephus in grain fields and will adjust their habits accordingly.

A braconid, *Microbracon cephi*, recently described by Mr. A. B. Gahan,[1] also attacks the larvæ in grass stems, kills them before maturity, and spins a gray parchment-like cocoon within the gallery, generally near its lower end. This cocoon is truncate at both ends, its disklike extremities completely filling the bore. The adult escapes by biting an opening through the stem in the vicinity of the cocoon.

ARTIFICIAL CONTROL

From the foregoing sketch of the life history of the western grass-stem sawfly it seems obvious that this pest will have to be attacked while it is in the larval state. The egg and adult stages are both brief and are clearly beyond the reach of control measures of any sort. For nearly 11 months the insect exists as a helpless larva, protected only by the grass or grain stem within which it lives. If this stem could be destroyed, the larva within would perish.

The first remedy that occurs to the farmer or the student of field conditions is the burning of the stubble in the autumn or spring. It would seem a very simple matter to set fire to the stubble and destroy at least the majority of the sawfly larvæ that are hibernating in it. But when one begins to examine the infested fields it is found that the inhabited stems have been cut at the ground level or below so that it is often necessary to brush away the earth in order to find the stubs containing the larvæ. So little heat is generated when stubble is burned that these subterranean stems could not possibly be harmed by the quick passage of the flames.

In 1907 Mr. Norman Criddle, in Manitoba, wishing to make a thorough test of this particular remedy, spread a layer of straw several inches deep over an infested area in a wheat field and set the straw on fire. More heat was produced than stubble alone could possibly make, the surface of the ground being too warm for the hand after the fire had died down. Even after this severe treatment it was found that, as far as could be learned by a minute search, not a single larva had suffered. They had simply retreated to the lower end of the hibernation cell and "kept cool."

Another fact must be noted in this connection. When a field has been damaged seriously by the sawfly, the stubble remaining to feed a running fire is of necessity more scanty than in an uninjured field

[1] Gahan, A. B. Description of a new hymenopterous parasite (Braconidæ). *In* Proc. Ent. Soc. Wash., v. 20, no. 1, p. 18–19. Jan., 1918.

and consequently it would be exceedingly difficult to burn such a field even under the most favorable conditions.

In Utah the bunch grass, *Elymus condensatus*, is much infested by this same fly and frequently is burned by fires that sweep the mountain side. This Elymus forms dense sods, with stems often more than 3 feet in length, and the heat from its combustion is great. The writer has examined a large series of burned sods and has seldom discovered any injury to the larvæ from the fire.

These facts would indicate the futility of burning the stubble as a control measure.

Although it might seem possible to decrease the numbers of the fly by mowing roadside and fence-row grasses during July, thus destroying the larvæ always present in the stems of these grasses, careful study has proved that a large percentage of the larvæ in these grasses is parasitized and therefore it would seem unwise to take steps that might diminish the number of parasites. Without any doubt grain fields in North Dakota and Canada are invaded regularly by sawflies that issue from grass growing along their borders. Still, because of the multiplication of useful parasites from this same grass it is probably inadvisable to mow the grass in midsummer.

Deep plowing, 5 to 6 inches, is perhaps the best remedy for the sawfly that can be suggested at present. It is much easier to advise this than to put it in practice. In almost every plowed field in any part of the country each furrow is marked by a row of stubble projecting from the inner edge of the furrow slice. Unless the stubble is turned squarely upside down, burying it at least 5 inches, the resulting surface at the same time being compacted by harrowing or rolling, the flies will be able to escape with ease from beneath the ground.

In the fall of 1916 the writer buried four lots of infested stubble in different depths of earth sifted and compacted by jarring. These were buried, one at 3 inches, one at 4, and 2 at 6 inches, in glass jars, 10 stubs in each of the first two, 20 in the other two. August 6, 1917, these cages were examined with results as follows:

Under 3 inches of earth all adults emerged.

Under 4 inches 1 larva died, all others emerged.

Under 6 inches 1 adult died in the cell, 6 larvæ also died, 2 active living larvæ still in the cell, all other adults emerged.

Under 6 inches 7 larvæ died in the cell, all other adults emerged.

Lumpy soil in the field might make it easier or harder for adults to emerge than fine soil in a jar, and this point might be difficult to determine.

Cultural conditions in North Dakota are not favorable for burying the stubble by plowing. Spring wheat is followed in many cases by winter rye which is disked into the wheat stubble after harvest. This procedure leaves all the infested stems of wheat on the surface, and nothing could be more favorable for the escape of the adult flies in the following spring. The wheat stubble seems to be necessary to hold the winter snow for the protection of the young rye, hence the farmers seldom or never plow the stubble under before sowing the rye.

Previous to the year 1919 it had been stated with much confidence by men who were known to be good observers that durum wheat was nearly immune from the attacks of the sawfly. On the strength of these statements county agents were inclined to recommend a modification of ordinary farm practice, at least to the extent of barring from that region Fife and Marquis and the softer-stemmed wheats in the hope that by this means the work of the sawfly might be checked and a more certain harvest assured. It was readily seen that an immune wheat would solve the problem of the sawfly.

Observations made by the writer during the month of August, 1919, and recorded on an earlier page of this paper, included in their scope an inquiry into this question concerning the immunity of durum wheat. Farm work was too far along at the date of this visit to permit of effective field work to settle the matter definitely, but several farmers informed the writer that durum had suffered severely that year, although not as much as either Fife or Marquis. These reports must be accepted at their face value since the agreement on this point was general.

The immunity of durum may vary from year to year and is possibly based on the relative dates of the appearance of the adult Cephus and the rapidity of growth of the young grain. The stem of the durum wheat is more dense and unyielding than that of other wheats, and if a warm rainy spring should hasten its growth it might prevent the sawfly from placing many eggs. A number of unknown factors enter into this problem that hinder its complete solution at the present time.

CEPHUS PYGMAEUS L.

In certain parts of the country the occurrence of *Cephus cinctus* appears to have been confused with that of its congener *Cephus pygmaeus*, a sawfly stem-borer that was probably imported from Europe only a few years previous to the first mention of *Cephus cinctus* in the United States. The habits of the two species are so similar that a brief synopsis of the life history of *Cephus pygmaeus* is given herewith together with a condensed description of the same insect.

As far as is now known the imported species does not yet occur west of the Mississippi River, while the western grass-stem sawfly has been found for the most part only west of the same river.

C. pygmaeus was first observed in 1887 in the vicinity of Ithaca, N. Y., and in 1889 Prof. J. H. Comstock published [1] an account of its life history as worked out by himself. From this bulletin the following summary of its habits and appearance has been compiled.

The adults, in the latitude of Ithaca, appear during the month of May and at once begin oviposition in the stems of wheat, just as the grain is jointing. In the majority of instances the eggs are placed above the third joint, and the larval gallery extends from the point of oviposition, or a little above, to the extreme base of the plant. By the time the wheat is ready to cut, early in July, a large majority of the larvæ have descended to a position below the level of the reaper cut and are safe from removal with the harvested straw. A week later nearly all the larvæ have girdled the stems within and part have already spun the silken lining of the hibernation chamber.

Cephus pygmaeus is a well-known species in Europe and has been described by both English and Continental writers. In France it has been considered a very serious pest and is said to attack both wheat and rye.

DESCRIPTION

Adult shining black, banded and spotted with yellow. Length of male 8 mm., of female 10 mm. Head large with prominent eyes; three ocelli near summit. Antennæ inserted on front nearly opposite middle of compound eyes, and composed of 19 or 20 segments. Wings transparent, iridescent, somewhat smoky, with costal margin yellow toward base. Mouth-parts (except tips of mandibles), a spot on clypeus, a narrow margin between compound eyes and mouth-parts, ventral aspect of thorax, legs (except a dark band on coxæ and femora), membrane at base of abdomen, caudal margin of each abdominal segment ventrally, a more or less well-marked spot on each side of first and second abdominal segments, a broad band occupying caudal three-fourths of third and fifth segments, a narrow band on caudal margin of sixth segment often more or less interrupted forming spots on back and sides, and latero-caudal angles of seventh segment, yellow in male.

In female, spots and bands usually smaller and sometimes entirely wanting ventrally.

Both this species and *Cephus cinctus* vary greatly in their markings. Mr. S. A. Rohwer, of the Bureau of Entomology, who has given much critical study to this genus and has examined a large series of individuals, mostly reared from known host plants, states in a recent publication: [2] "The introduced, European, *Cephus pygmaeus* (Linnaeus) is very similar to the native species common throughout the west and it is difficult to find characters which distinguish the two in all their forms."

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[1] Comstock, J. H. A saw-fly borer in wheat. *In* Bul. 11, Agr. Exp. Sta. Cornell Univ., Nov., 1889.

[2] Rohwer, S. A. The American species of the genus Cephus Latreille. *In* Proc. Ent. Soc. Wash., v. 19, p. 139–141. 1917.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 842

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER September 7, 1920

THE NEMATODE DISEASE OF WHEAT CAUSED BY TYLENCHUS TRITICI.

By L. P. Byars, *formerly Pathologist, Office of Cotton, Truck, and Forage Crop Disease Investigations, in cooperation with the Office of Cereal Investigations.*

CONTENTS.

OCCURRENCE OF THE DISEASE.

A disease of wheat caused by the nematode *Tylenchus tritici* (Steinbuch) Bastian has been known for many years in certain European countries, where it causes considerable damage. The disease manifests itself most strikingly in the wheat heads. Here rather small dark-colored galls of the same general shape as wheat kernels are formed in place of normal grains. It is also known to affect other aerial parts of the wheat plant, but does not attack the roots. In thrashing, many of the nematode galls thrash out with the wheat. Examinations by the writer of numerous samples of wheat collected during the winter of 1917–18 by the Office of Grain Standardization, of the Bureau of Markets, at mills and other places, revealed the presence of many of these galls and showed for the first time that the disease occurs to a serious extent in certain localities in the United States, particularly in Virginia. Subsequent observations in the field have shown that the pest in some instances destroys more than 40 per cent of the growing wheat. It therefore seems de-

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sirable and timely to bring to general attention the data at hand, so that the disease may be more readily recognized, its further importation and distribution prevented, and its control understood.

HISTORY.

Needham (24),[1] in 1743, in making microscopic examinations of supposedly smutted grains of wheat, found that they contained numerous motionless, eelworm larvæ instead of spores. When placed in water these larvæ soon began eellike movements; hence, there is this definite evidence of the occurrence of the disease in England at this early date. At that time Needham briefly recorded his observations and again in 1745 (25) described the results of further investigations, but was unaware of their full significance until Roffredi in 1775 (30) and 1776 (31) published the result of accurate investigations covering several years, which clearly showed for the first time the causal relation of the nematodes to the malady and shed considerable light on the life history of the parasite. In 1799, Steinbuch (34) dealt with a disease of wild grass caused by a nematode which he called *Vibrio agrostidis* and considered different from the wheat eelworm. He appears to have been the first investigator who proposed a name for the latter organism. He first refers to the parasite in these words, " und welche *Vibrio tritici* genannt werden konnte," and subsequently uses the name *Vibrio tritici* many times and in such manner as to show conclusively that it is the wheat nematode of which he is speaking. Bauer (3), in 1823, after considerable study of and experimentation with the organism, also named it *Vibrio tritici*, apparently unaware of the fact that it had been previously thus designated by Steinbuch. Although Steinbuch was the first to apply the binomial, Bauer seems to have been the first to use the name systematically for the parasite. This doubtless accounts for the fact that many later investigators cite him (Bauer) as authority for the species. Dujardin (13), in 1845, transferred the species to the genus Rhabditis. Rhabditis is a genus described by Dujardin and contains mostly free-living forms which have little in common with Tylenchus. Diesing (12), an eminent systematic helminthologist, in 1850 also made a similar classification of the parasite. He placed it in the genus Anguillula described by Hemprich and Ehrenberg. This genus contains the vinegar eel and other free-living forms. Assuming that the parasite occurred on other grasses than wheat, he accordingly called it *Anguillula graminearum* Diesing. In his classical monograph, Bastian (2) in 1864, correctly transferred the old species name as used by Steinbuch, i. e., *tritici*, to the genus Tylenchus.

[1] The numbers in parentheses refer to " Literature cited " at the end of this bulletin.

The correct designation, therefore, becomes *Tylenchus tritici* (Steinbuch) Bastian. Two years later, in 1866, Schneider (32) gives the scientific name of the organism as *Anguillula scandens.*

In view of the above brief résumé of the work of those investigators who took some part in naming the parasite, its proper synonymy chronologically recorded would seem to be as follows:

Tylenchus tritici (Steinbuch) Bastian, 1864.
- *Vibrio tritici* Steinbuch, 1799.
- *Vibrio tritici* Bauer, 1823.
- *Rhabditis tritici* Dujardin, 1845.
- *Anguillula graminearum* Diesing, 1850.
- *Tylenchus tritici* Bastian, 1864.
- *Anguillula scandens* Schneider, 1866.

Following Roffredi's (31) publication of 1776, many papers on the disease appeared in European literature, some of which have been mentioned. They were for the most part discussions as to the correctness of the observations of Roffredi, and contributed little to what was already known about the trouble until the monograph of Davaine (11) appeared in 1857. In it he gives practically all that is known to-day about the etiology of the disease, lucidly describes and illustrates the different stages in the development of the parasite, and records the results of physiological researches on the nematode which furnish a basis for its control. His work largely silenced the discussion that had prevailed in the literature as to the cause of the disease, some investigators having confused the trouble with stinking smut of wheat (*Tilletia tritici*).

Many papers appear in European literature after Davaine's publication, but in general they deal mainly with the occurrence and distribution of the disease and add little to what had previously been recorded. Marcinowski's (22) valuable contribution of 1909, however, added considerably to our knowledge of the pathogenicity and physiology of the parasite. Since that time no publications of major importance relating to the disease have been found.

In the United States the occurrence of the eelworm disease of wheat seems to have been first recognized by Johnson (19), who in 1909 recorded that it had been found in California by members of the staff of the Office of Cereal Investigations of the Bureau of Plant Industry, and had been authentically reported to him to occur in New York, Georgia, and West Virginia. There appear to have been no other records of the trouble in North America until Fromme (14) in 1917 published a short note stating that he had found it at one point in Virginia. Since that time the writer (7, 8) has reported its wide prevalence in Virginia and its limited occurrence in other States, has described the general nature of the disease, and has pointed out control measures. Later, Coleman and Regan (10) contributed to our knowledge of the disease so far as it affects the marketing and milling of wheat. A similar disease of several other grasses, thought to be due to a closely related or identical species of nematode, was reported by Bessey (4) in 1905 and later by the writer, but recent investigations indicate that the organisms producing the malady in wheat and other grasses differ physiologically, if not morphologically. The writer's acquaintance with the disease on wheat began in 1915, when minor inoculation experiments were conducted in the greenhouse with material received from China. Interest was renewed during the winter of 1917–18 as the result of finding, in cooperation with the Office of Grain Standardization, an abundance of material in the United States. Consequently, previous experiments in the greenhouse were repeated and extended, laboratory investigations carried out, and field observations made. These studies are being continued.

DISTRIBUTION.

The nematode disease of wheat is of almost world-wide distribution, having been reported from all continents except Africa. Sorouer (33), in 1913, stated that it had been found in France, Germany, Austria, Hungary, Switzerland, Italy, Sweden, Holland, England, and North America. Dr. N. A. Cobb[1] has found it many times in Australia and the writer (6) in 1917 reported its occurrence in China. Through the courtesy of Dr. C. E. Leighty, of the Office of Cereal Investigations, Bureau of Plant Industry, an examination of all samples of wheat imported by the United States Department of Agriculture for the past 25 years or more was made and, besides finding the disease in material obtained from some of the countries listed above, it was also found in importations originating in Russia, Turkestan, and India, from which places no reference to its occurrence has been seen. Averna-Sacca (1) in 1912 stated that it occurs in Brazil. From the foregoing account it is evident that the disease can exist under very different climatic and soil conditions and that it is at present of extremely wide occurrence.

Indications are that the disease has been introduced into this country. That it may be endemic in Europe is suggested by the fact that it was not reported elsewhere for nearly a century after its discovery there. It seems likely that it was first introduced into this country with importations of seed wheat from England or continental Europe. The exact native habitat of the disease, however, is an interesting and open question which may never be definitely an-

[1] In conversation with the writer, Dr. Cobb stated that he had found the trouble on wheat in Australia in 1892.

swered. In this connection it is of interest to note that a careful examination by the writer of a considerable collection of native emmer, or so-called "wild wheat" (*Triticum dicoccoides*), from Palestine failed to reveal the disease.

Within the United States the disease was first found in 1909 at Modesto, Calif., and Old Fields, W. Va. During the same year it was reported from New York and Georgia. As a result of cordial cooperation by the Plant Disease Survey of the Bureau of Plant Industry and the Office of Grain Standardization of the United States Department of Agriculture and by pathologists and other agricultural agents of various States, the writer has recently examined specimens

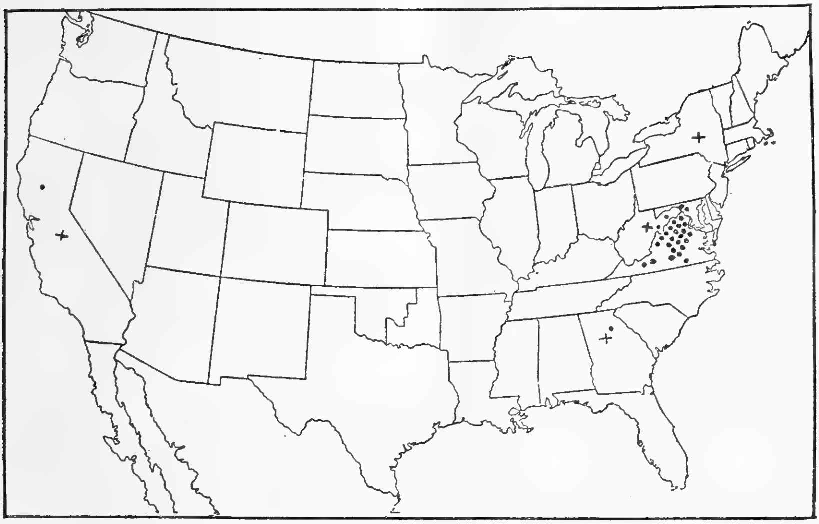


FIG. 1.—Outline map of the United States, showing the distribution of the wheat nematode. The dots represent the States where it was found during 1918, while the crosses indicate the localities in which the disease was reported in 1909.

from Red Bluff, Calif., from two counties each in West Virginia and Maryland, from one county in Georgia, and from a large number of widely separated places in Virginia. Distribution of the trouble in this country is graphically shown in figure 1. Whether the malady occurs only on the east and west coasts and not in the great wheat-growing States of the Middle West is not now known. It may be possible that the trouble exists in the Central States to a limited extent and has been merely overlooked or mistaken for stinking smut or other troubles, or it may not occur there as yet. As the disease apparently is not endemic in the United States, nor especially widespread as yet, every effort should be made not only to prevent its further importation into and spread within this country, but it should be eradicated as far as possible from localities already infested.

ECONOMIC IMPORTANCE.

Economically this wheat disease is of considerable importance in certain countries and of very minor significance in others. In central Europe, especially in Germany, where the trouble was found soon after its discovery in England, reports during the last decade indicate that the disease caused little damage. Earlier writings, however, show that it was responsible for severe losses. Haberlandt (15) in 1887, for example, reported that of 3 samples of wheat collected from as many Provinces in eastern Germany, 20 contained considerable quantities of the diseased kernels.

Doubtless improved methods of cultivation and sanitation and the general agricultural practices in combination with a knowledge of means of controlling the disease are responsible for its apparently minor economic status in central Europe in recent years. In England, where conditions seem to have been rather favorable for its development, the malady now appears to be well controlled, although, as in Continental Europe, writers during the eighteenth century report its serious prevalence at times. Judging from the examination of small lots of wheat shipped from Russia, Turkestan, and India, it occurs in these countries to a considerable extent. Reisner[1] in 1915, without knowing its cause, reported that the malady at that time was the cause of severe losses in certain parts of China.

During the past year the disease has been found to be the cause of heavy losses at certain places in the United States. Lots of wheat sent in from or collected by the United States Department of Agriculture in Virginia contained, according to count, from a fraction of 1 per cent to more than 50 per cent of the nematode galls. These findings, together with the fact that many of the galls are lost before and during thrashing and that there are many direct losses caused to the crop in the field by the disease not shown by the thrashed grain, suggest much more severe damage than that indicated by the percentage counts referred to above. During the summer of 1918 the writer found several fields in one locality in Virginia in which about half of the wheat heads were severely infected, and, in addition, many of the plants were killed.

DESCRIPTION OF THE DISEASE.

The nematode disease of wheat manifests itself only on the aerial parts of the host. It affects directly both the young and old leaves as well as the embryonic fruit, and may indirectly cause a bending or crooking of the stem. On seedlings mildly infected it usually

[1] Dr. H. J. Reisner, of the University of Nanking, Nanking, China, in a letter transmitting specimens to the Office of Cereal Investigations, states that the disease causes great damage in some Chinese Provinces.

produces a wrinkling, twisting, and rolling of the younger leaf blades, as shown in Plate I, *A* and *B*. Small raised, rounded areas may appear on the upper surface of such leaves, which lose their normal green color, become yellow, wilt, and die. Very young leaves sometimes, however, show conspicuously none of these symptoms. Occasionally they contain light-colored swellings or galls, one or more of which may be located along the midrib, on the leaf edge, or between the two, and are misshapen by an unequal lateral development. A conspicuous gall on the edge of a leaf is shown in Plate II, *A* and *B*, and apical swellings near the midrib of a young leaf 16 days after artificial inoculation are depicted in Plate II, *C*. By tearing apart these leaf galls several weeks after they have been induced, the eelworms which cause them can be found in all stages of development.

When seedlings become more severely attacked than already indicated, more pronounced evidence of abnormality appears. The young leaves become so strongly infected within the older leaf sheaths that instead of growing straight up normally they may be forced through the latter, carrying along with them the young stem. In this way stems sometimes are bent and induced to grow in an almost horizontal direction. The leaves become so wrinkled, twisted, and rolled as to lose all semblance of their natural shape. Their normal green color then disappears and finally, after wilting, the entire plant dies. Diseased leaves sometimes roll so tightly as to hold firmly the tip of the younger leaves. This results later in wrinkling and more or less telescoping of these leaves as they grow from below.

Leaf and stem symptoms of the disease occur more commonly on the seedlings than on the older plants, which leads to the general belief that the former outgrow the trouble. Marcinowski (22), however, does not agree with this, and after conducting an experiment in which 90 per cent of the infected seedlings died while still young, concluded that as a rule plants succumb before maturity when diseased at an early stage of growth. At any rate, leaf and stem symptoms of the disease are less common, as well as less noticeable, on the older plants. Maturing plants may be decidedly dwarfed, however, somewhat yellow in color, and show a curling of the upper leaves, as may be seen in Plate I, *C*.

Leaf rolling, however, which is of more frequent occurrence than the dwarfing and yellowing, is not always an indication of the nematode disease, since it may be caused by other factors. While leaf symptoms usually occur, they may be entirely absent, and yet, at the maturity of the plant, the head may be found to be severely infected.

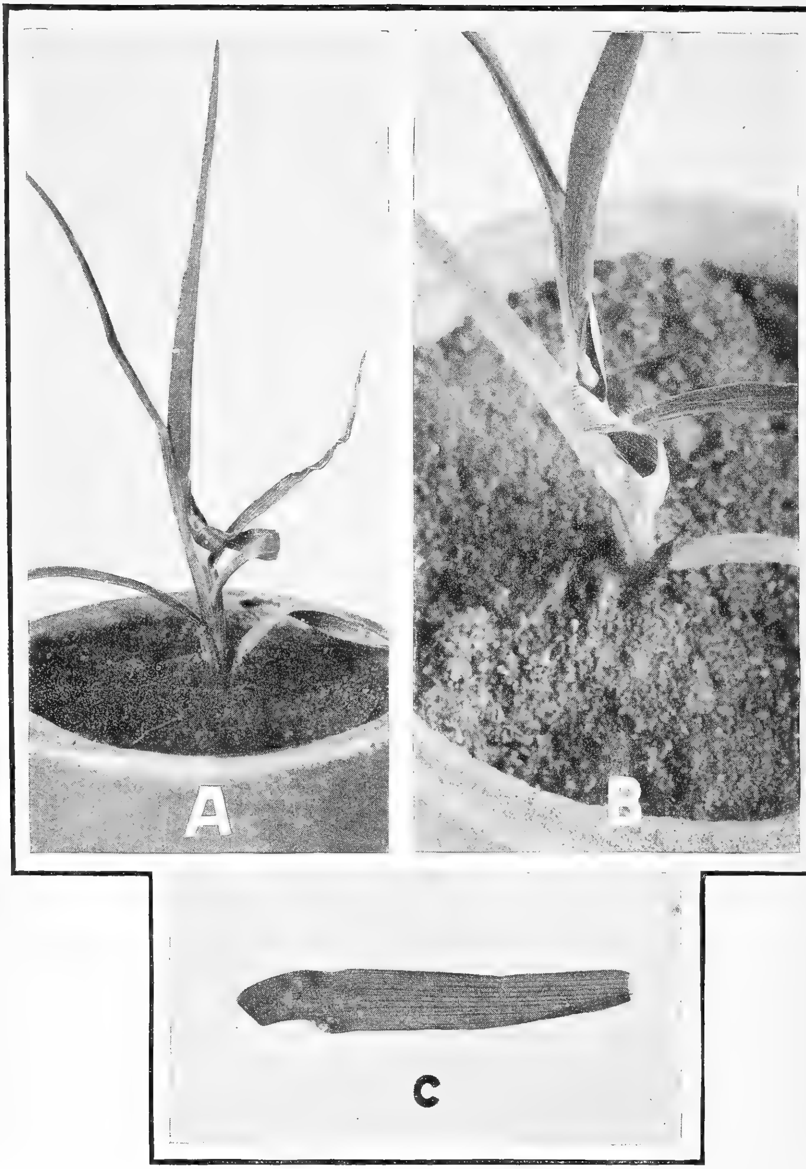
Most positive and clear evidence of the disease can be detected by a careful examination of the heads of the plant at maturity. Diseased spikes (Pl. III) are usually reduced in size, especially in length, remain green longer and therefore mature somewhat later than the normal ones, and the glumes protrude decidedly outward and give a somewhat thickened appearance to the shortened spike. Depending upon the severity of attack, some or practically all flowering glumes on infected heads contain, in the place of normal kernels, hard, light-brown to dark-colored galls which are filled with nematodes. These galls, though usually slightly furrowed on one side, somewhat as are wheat kernels, are shorter and not uncommonly thicker. This thickness of the galls often results in the spreading of the inclosing glumes so as to expose the galls to almost full view. As a consequence of this, wheat heads thus infected may be readily detected in the field. When young, the galls are light to dark green in color. They gradually become dark brown later, as the normal wheat heads ripen. Because of a general similarity, they were in France first confused with and mistaken for "smutted" wheat and called "blé niellé," but only a simple test is necessary to distinguish the two. A smutted grain is easily crushed by a little pressure and becomes a mass of smutty powder, the black spores, whereas the galls are hard and firm and break with difficulty. In Germany the galls were first associated with the seed of cockle (*Agrostemma githago*), a weed found commonly growing in wheat. This resulted in the disease being designated there as "Radekrankheit." Only a cursory examination, however, is necessary to distinguish the smooth nematode galls from the black cockle seeds, which are covered with rows of short spines. In England the trouble is perhaps most commonly called "purples," on account of the color of the galls. Farmers and millmen in sections of this country where the disease occurs call wheat containing these galls various names, such as smutted, bunted, cockle, bin-burnt, and immature wheat. There have been instances, some of them recorded, where pathological investigators in this as well as other countries, without making microscopic examinations, wrongly identified the galls as stinking smut of wheat (*Tilletia tritici* or *T. levis*). Some of the differences in size, shape, color, and general appearance between the nematode galls and the material for which they have been mistaken are shown in Plate IV.

DIFFERENCES BETWEEN THIS DISEASE AND TULIP-ROOT.

It seems desirable to point out differences between the malady discussed in this paper and the so-called stem disease, or "tulip-root," of wheat and other cereals, which, while occurring in European countries, has not been reported on wheat in America. The two troubles have been confused both popularly and scientifically, doubtless owing to their occurrence together at times and

LEAVES OF WHEAT PLANTS AFFECTED BY TYLENCHUS TRITICI.

A, Month-old seedling from the greenhouse, inoculated by placing a few drops of water containing larvæ on the seed when planted. Note the abnormal wrinkling of the central leaf. *B*, Leaf from an infected greenhouse seedling, showing the characteristic wrinkling, rolling, and twisting caused by the nematodes. *C*, Part of an almost mature field-grown plant the head of which contained many nematode galls. The upper leaf often is found tightly rolled on such plants.



WHEAT SEEDLING AND LEAF INFECTED BY NEMATODES.

A, A five-weeks'-old wheat seedling from a greenhouse, artificially infected with *Tylenchus tritici* and decidedly dwarfed as a result. Observe that the twisted central leaf is held in the next older leaf sheathed by a nematode gall on its edge and that the small upper leaf on the right is distorted, wrinkled, and twisted. Photographed May 31, 1918. Natural size. *B*, Part of the plant pictured in *A*, enlarged to show the location, shape, and size of the nematode gall on the central leaf and contiguous portions of the infected leaf. × 2. *C*, Leaf blade of a wheat seedling, showing the one-sided apical development and small nematode galls as a result of artificial inoculation in the greenhouse. Photographed in October, 1917. × 2.

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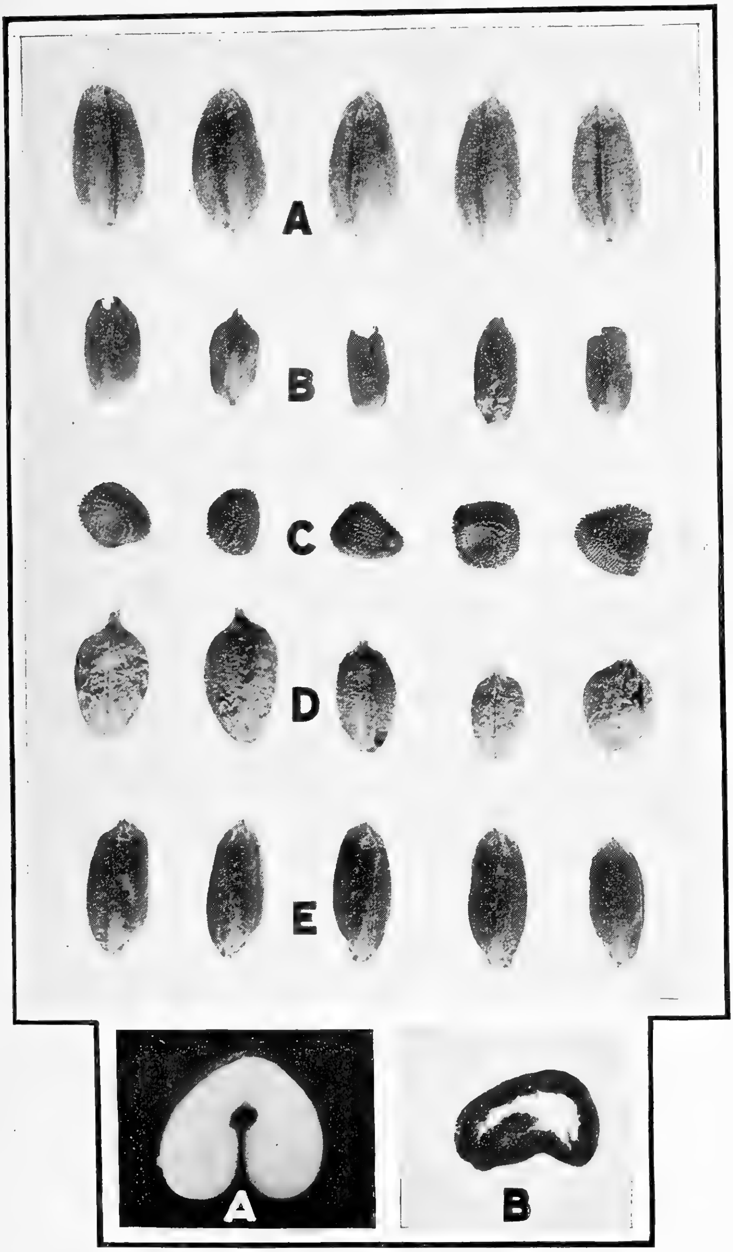
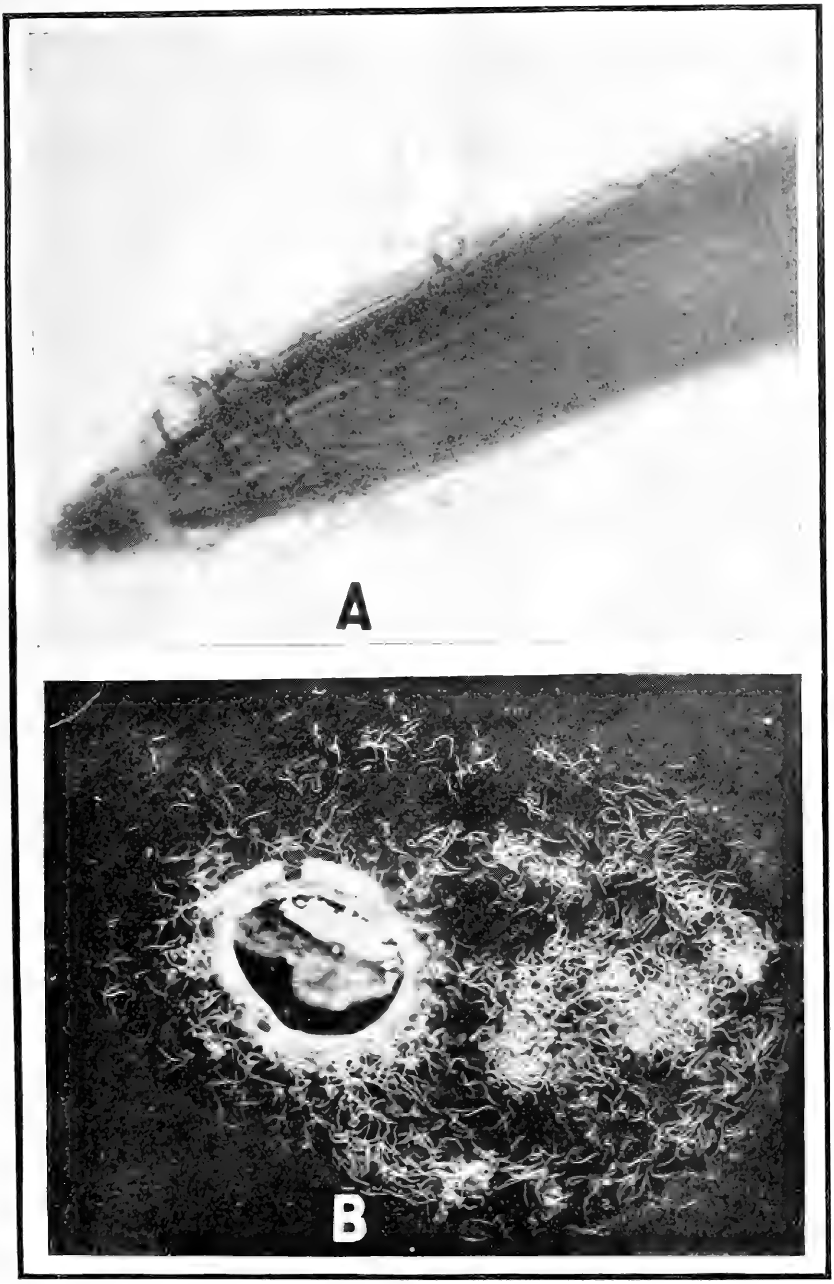
WHEAT SPIKES, INFECTED AND HEALTHY.

A normal head of Leap Prolific wheat between two nematode-infected heads of the same variety. Material collected just before harvest at Remington, Va., June 17, 1918, and painted natural size.



Normal Kernels of Wheat with Nematode Galls and Objects for which the Latter have been Mistaken.

Fig. 1 (above).—*A*, Normal kernels of wheat; *B*, dark, smooth nematode galls; *C*, black papillate seeds of cockle; *D*, smutted wheat grains (smut balls); and *E*, bin-burnt kernels. Compare the sound wheat with the nematode galls and note the pronounced difference between the latter and the cockle seed, smutted grains, and the bin-burnt kernels for which the nematode galls are often mistaken. Twice natural size. Fig. 2 (below).—*A*, Unstained, thick cross section of a normal wheat kernel; *B*, cross section of a flower gall filled with a white mass of nematodes, for comparison as to shape, size, and content. × 6.



LARVÆ OF TYLENCHUS TRITICI.

A, Photomicrograph of the root of a wheat seedling growing in a tube of plant-nutrient agar and showing active eellike larvæ accumulating about the root tip. The writer was unable to produce infection through the root, however. × 45. *B*, Masses of milk-white threadlike larvæ photographed while actively moving about in a few drops of water after having escaped from the portion of a cut-open flower gall shown near the center of the photograph. × 6.

LARVÆ OF TYLENCHUS TRITICI.

A, Photomicrograph of an unstained cross section, 15 μ in thickness, of a nematode flower gall, showing larvæ in the center unattached to the inclosing host walls. × 37. *B*, Photomicrograph of active larvæ from a flower gall moving in a drop of water. Note their transparent anterior ends and their tapering, slightly pointed posterior ends. × 30.

because they are both caused by related species of nematodes. Tulip-root is induced by another parasitic eelworm, the so-called stem and bulb infesting nematode, *Tylenchus dipsaci* (Kühn) Bastian. This the writer has found in this country on hyacinths, strawberries, clover, and other plants, but not on wheat. Ritzema Bos (29), however, noted the disease on wheat, but described it more in detail as it appears on oats. He notes that on wheat it produces a swelling near the base of the plants, resulting in what he calls a tulip-root appearance. He also states that definite discolored areas result on the stems and leaves. The flowering parts, however, usually are not attacked. As these two closely related wheat diseases differ so strikingly in the way they affect the plant, especially as the so-called "tulip-root" disease does not produce flower galls and the other does, the two diseases are readily distinguishable.

ORIGIN AND DESCRIPTION OF THE GALLS.

The nematode galls may be short and thick or long and slender, and in a dried condition they are nearly always smaller than the wheat kernels. Dwarfed simple galls little more than the size of a pinhead are sometimes found, while those nearly as large as wheat grains are met with frequently. Their size is mainly dependent upon the number of larvæ which enter them, as well as upon the time when and place where the latter penetrate the tissues.

Investigators differ as to the origin and nature of the tissue constituting the flower gall. Davaine (11) thought that the larvæ might enter any portion of the flower and that, therefore, the composition of the resulting gall merely depended upon what tissues were invaded. Haberlandt (15) considered the galls to be largely, if not entirely, of ovarian origin, while Prillieux (28) believed them to be derived only from staminate tissue. Marcinowski (22), after careful and constant macroscopic observations throughout the development of the galls, concluded that they may arise (*a*) from the undifferentiated flower bud, (*b*) at a later stage from staminate tissues which are first differentiated, (*c*) from carpellate tissues which are formed last, and (*d*) from tissue lying between the stamens or between the carpels and stamens. Based on an examination of matured galls as they occur in the wheat spikes, the writer's observations and interpretations agree in the main with those of Marcinowski (22).

Galls within the same flower may be simple; that is, may contain only a single cavity filled with the organism, as shown in Plate V, *B*, and in Plate VI, *A*, or they may be complex. The latter are composed of two or three of the single galls whose walls have grown together and usually show separate interior cavities, as well as deep external furrows, along the lines where the separate units have coalesced. The simple galls are by far the more common and usually occur singly in each flower, although as many as three separate galls have been found in a single flower. Sometimes a young gall may be seen developing in place of one stamen, while the other two stamens and the pistil still appear almost normal. It is rather rare, however, for a normal kernel and one or more galls to develop within the same flower. A young gall is not uncommonly found in place of each of the three stamens, and later these may produce a single trilobed compound gall. In such cases ovarial developments are absent. More commonly, however, a single gall is initiated either in the ovary or the young staminate tissues, and it then usually causes atrophy or nondevelopment in the other reproductive parts of the flower.

Only the reproductive organs or adjacent tissues of the flowers have been found affected, but every flower on a spike may be invaded. It is not uncommon, therefore, to find every flower of a mature spike containing nothing but galls. Heads of wheat well infected with larvæ are often reduced in size, have their glumes sticking out at a greater angle from the rachilla than normal ones, and mature somewhat later than the uninfected spikes. Because of their thickness, the dark maturing galls are often not entirely covered by the glumes, so that they become exposed and thus serve as a conspicuous symptom whereby infected spikes may be readily distinguished in the field (Pl. III).

CAUSE OF THE DISEASE.

The cause of the nematode disease discussed in this paper may be readily seen with the unaided eye when the contents of a gall are placed in clear water. With the aid of a hand lens, the milky white fibrous mass thus liberated, as shown in Plate V, *B*, can be readily observed to consist of thousands of straight or curved threadlike elements, the larvæ of the nematode *Tylenchus tritici* (Steinbuch) Bastian. If watched carefully they will be seen soon to begin active eellike movements. Occasionally among a white mass of larvæ from a mature gall one may see with the naked eye the brown misshapen remains of adult males and females, and with the assistance of a microscope find a few eggs, the stage from which the larvæ developed. In young galls, living adults of both sexes and an abundance of eggs and larvæ may be found.

EGGS.

When viewed from the end the eggs seem to be almost perfectly circular in cross section. In lateral view, which is that most commonly seen (fig. 2), they are elongate, granulated bodies, usually symmetrical in shape. They are usually about twice as long as broad, although individual eggs vary considerably in size even within the same gall. This, however, is not surprising when it is considered that these eggs in a gall may be laid by a number of different females. In three lots of eggs obtained from mature galls collected at widely separated points the writer noted a variation in length from 73 to 140 μ and in width from 33 to 63 μ. An average of all measurements made from material collected in the United States was 38.7 by 85.1 μ, while an equal number of observations taken on eggs from a single lot of galls collected in China gave slightly lower averages, namely, 37.4 by 71 μ. These figures agree very well with those obtained by Bauer (3) in Europe, the dimensions given by him being 28 to 31 by 83 μ (1/800 to 1/900 by 1/300 of an inch). Although the different figures agree in general, there is yet perhaps enough difference to warrant the suggestion that definite strains of the nematode may possibly occur. This suggestion finds further support in data later presented which show what appear to be consistent differences in the dimensions of larvæ collected from various parts of the world. Supporting evidence of possible strains of the organism is also found in certain physiological variations.

FIG. 2.—Lateral view of an old egg, measuring 95 by 40 μ. Camera-lucida drawing. × 190.

The eggs contain dense rounded granules, are semitransparent, and possess a single central light spot, the nucleus. They are covered by a tough, transparent, plastic coat or skin, probably chitinlike in nature, but, unlike the eggs of another endoparasitic nematode, *Heterodera radicicola* (Greef.) Müller, they can not withstand highly unfavorable conditions. This may be due to their not being oviposited in a gelatinous protective secretion, as is the case with the latter, and to their very rapid development. Just how long it takes an egg to develop from the 1-celled state to an active larva is not known. Segmentation, however, is rapid, probably requiring not more than a few days at most, and it ordinarily takes place after oviposition. Within a short time after the egg is deposited it develops into an active larva which pierces the egg coat with its anterior end, escapes, and leaves behind an empty transparent shell.

LARVÆ.

Freshly hatched larvæ are transparent, threadlike animals usually a little more than one-half millimeter in length. Such of their organization as can be observed at low magnification is shown in figure 3. In this first stage, which is of short duration, the larvæ are very delicate, frail, and weak, and ill adapted to withstand unfavorable environmental conditions. They develop quickly into the so-called second larval stage, presumably by going through one or more molts.

It is in this second stage that the larvæ are found as they occur in mature flower galls of wheat, a cross section of one of which is shown in Plate VI, *A*. These larvæ, Plate V, *B*, are slender, cylindrical to spindle shaped animals, slightly blunt at the anterior end, but tapering to a fine point at the posterior end. An outline drawing of a single specimen which measured 884 μ in length is shown at a magnification of 190 diameters in figure 4. In their greatest width the larvæ are from 15 to 20 μ, or about one forty-fifth of the average length, which is from 850 to 890 μ. Based on the measurement of 184 individuals taken from 16 lots of galls collected at as many different localities, the writer found an average length of 869 μ, the extremes being 770 μ and 966 μ. These figures are somewhat smaller than those suggested by Marcinowski (22), who gives the uncertain average larval length of about 1 mm. Dimensions of larvæ from European as well as American material are somewhat larger than those observed by the writer with similar material from China. The average of all measurements of larvæ from a single lot of galls from one point in China was found to be 793 μ, with a maximum range in length from 658 to 910 μ. The dimensions of these larvæ from China are thus seen to average slightly smaller than those examined from other sources. This is similar to the condition pointed out for the eggs from the same material, namely, that they, too, average somewhat smaller. The above indicates that possibly there may exist morphologically different strains or varieties of the organism in different geographical regions.

As is the case with most nematodes parasitic on plants, the structure of the

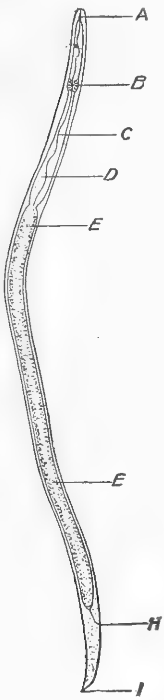


FIG. 3.

FIG. 4.

FIG. 3.—Young larva, 500 μ in length, which has just emerged from the eggshell. Camera-lucida drawing of lateral view. × 190. For an explanation of the letters *A* to *I*, see figure 4.

FIG. 4.—Old larva, 884 μ in length. Camera-lucida drawing of lateral view. × 190. *A*, Hollow probing spear, through which food is sucked; *B*, muscular esophageal bulb functioning as a pump in sucking food through the spear; *C*, esophageal canal; *D*, posterior esophageal bulb; *E*, digestive system; *F*, nuclei of cells comprising the intestine; *G*, reproductive system at an early stage; *H*, anal opening; *I*, tail.

larvæ of the wheat nematode is comparatively simple. In general, earch larva consists of an outer tube or body covering, within which is a second smaller tube, the digestive tract. The space between the walls of these two tubes is known as the body cavity. Anteriorly, the digestive system opens at the end of the animal, while posteriorly it opens at the anus, or vent, about 50 μ from the point of the tail (fig. 4). A buccal spear (9 to 11 μ long) pointed at the forward end and trilobed at the other, is located at the anterior end of the digestive system (fig. 4, *A*). By means of this hollow spear, which can be exserted and retracted by strong muscles, the larva is able to pierce its egg membranes, to force its way into plant tissues, and by means of the fine canal which extends through the spear to absorb plant juices or other liquid foods. Connected to the base of the spear is the rather slender esophagus, which is about one-quarter the entire body length. About midway of the esophagus is an almost spherical muscular-walled enlargement known as the esophageal bulb (fig. 4, *B*). Near the center of this is a small valve capable of expansion and contraction by the muscular wall of the bulb. By means of a pumplike action of the bulb, liquids are sucked through the spear and esophagus and forced into the intestine. Just back of the esophageal bulb, the esophagus is slender and practically cylindrical, but toward its posterior end it enlarges gradually into another bulb known as the posterior esophageal bulb (fig. 4, *D*). A large light-refractive cell, which functions as a salivary gland, is located near the base of this swelling. This posterior esophageal bulb joins with the much larger tubular intestine, which almost completely fills the posterior three-fourths of the tube of the body wall (fig. 4, *E*). The diameter of the intestine corresponds directly with that of the larva except at its posterior end, where the intestine is contracted into a fine channel, the rectum, which terminates at the anal opening. The intestine contains translucent, granular matter, presumably reserve food, in the form of fatty globules and other materials. The body cavity of the animal not occupied by the digestive system is for the most part practically transparent. Usually a row of refractive nuclei of cells composing the intestinal wall can be plainly seen, and this, together with the half-moon shaped light zone located about midway between the ends of the intestine, distinguishes the larva of this nematode from those of any other species occurring on wheat. No known sexual differentiation occurs in larvæ of the stage just described, although the primordial reproductive organs, consisting of a few hyaline cells located in the half-moon shaped light zone, already mentioned, are always visible. Within the galls, as they mature and dry out, the larvæ, all of which appear to have reached about the same degree of development, become externally desiccated, motionless, and partly coiled. In this condition they are capable of remaining dormant for many years. The writer has recently reactivated in water such larvæ from galls which had been imported along with wheat from Turkestan in 1910. According to Needham (26), a "M. Baher" in 1771 secured vital movement in specimens which the former had sent him 27 years previously, in 1744. During this period the larvæ had been kept in protective galls in the laboratory. When mature galls previously soaked in water are opened, the larvæ upon being freed immediately straighten out with a mechanical movement and later, sometimes within a half hour or occasionally only after a day or more, begin their sluggish eellike vital motions. The two types of movements, though distinctly different and due to different causes, have nevertheless been confused even by trained observers. Dead larvæ may show the former—that is, the mechanical straightening—in a manner very similar to live ones, but only living larvæ show the vital, eellike movements. Very probably, however, "M. Baher" in observing the 27-year-old material referred to above saw both the mechanical and vital movements.

Moistened or submerged in water the larvæ move actively (Pl. V, *B*), but not in the rapid manner so typical of free-living forms. After being held in distilled water at room temperature for more than two months, the writer has observed them still sluggishly moving. During this time the only change noticeable was in transparency, caused undoubtedly by the utilization of reserve food. The translucency increased with the length of time of immersion until finally, at the last observation, they were almost transparent. Liberated in soil under natural conditions, they are capable of living in a free state much longer. Marcinowski (22) concluded from carefully conducted experiments that they could probably live thus in an active condition for seven months or more. In the application of control measures for the wheat nematode, as for the root-knot nematode (*Heterodera radicicola*), use can be made of the fact that these active larvæ will starve to death in a comparatively short period.

Although capable of living free in the soil or elsewhere for several months, the larvæ undergo no development until the host plant is penetrated. By their own eellike locomotion they travel through the soil in search of wheat seedlings, and numerous larvæ finally become located between and within the leaf sheaths near the apical growing points of the culms. They may use the roots as a means of elevating themselves to other parts of the host, but, contrary to what Roffredi (30) and other investigators thought, do not normally penetrate them. The writer was unable to produce root infection by placing large numbers of active larvæ on the surface of sterile tubes of a plant nutrient agar containing wheat seedlings. In such cultures the organisms were observed to move about freely through the transparent medium and to accumulate about the seedling roots, mostly near the root tips, as shown in Plate V, *A*, but no penetration was observed. There was not, however, the marked accumulation about the root tips which the writer (5) has previously observed when pure cultures of the root-knot nematode (*Heterodera radicicola*) were inoculated in similar tubes containing tomato plants. In the latter case there seemed to be some sort of stimulus, possibly chemotactic, attracting the larvæ to the growing point of the root, which many of them entered. Many examinations of wheat seedlings growing in the greenhouse in soil well infested with larvæ of *Tylenchus tritici* showed no root infection.

After having reached the aerial portions of their young host plants some of the wheat nematode larvæ may enter the leaves, but most of them locate in large numbers at the base of and between the leaf sheaths near the terminal growing bud. Here they remain in an ectoparasitic condition, ready to attack the wheat heads as they develop. Thus, contrary to what is commonly thought, the organism of itself travels only a short distance, possibly less than an inch sometimes, in reaching the wheat spikes. The exact manner by which larvæ enter the leaf or flower tissues has never been observed. As there appear to be no natural openings, such as stomata, large enough to permit their entrance, it must be assumed that they get into the inner tissues either by artificial openings or, as is much more likely, by a piercing of the cells with their spearlike anterior ends. At the same time they may possibly secrete some substance to assist in breaking down the cell walls. Only the young, actively growing tissues and cells are invaded.

Wherever larvæ penetrate the leaves, an increase in the size and number of host cells takes place, resulting in a local gall. One or more of these galls may be formed on a single leaf, and they may be located on any portion of the latter, depending upon the place and time of larval penetration. The larvæ usually enter only the young leaves which are entirely inclosed within the older leaf sheaths. Their entrance somewhat retards and prevents normal development, causing the leaves to grow unevenly and to become wrinkled, rolled, and distorted. These symptoms are illustrated in Plate II, *A* and *B*, which in addition shows a small gall on the edge of the youngest leaf. This gall, which is typical, is about 4 mm. long, 3 mm. wide by 2 mm. thick, and has lost its normal green color, being almost white. Upon teasing it apart 25 of the nematodes were found in various stages of development, including sexually mature females almost ready to lay eggs. This, however, is an unusually large number to find in a leaf gall.

Ordinarily a wrinkling and rolling of leaves on infected seedlings is not accompanied by the production of leaf galls, and one may search in vain to find larvæ within these wrinkled leaves. In just what manner the parasite induces this wrinkling without remaining in the leaf is not known. It may possibly be the result of the extraction of food substances in the form of plant juices from the leaves by the larvæ when the leaves are young and inclosed in the outer leaf sheaths.

While the leaves are sometimes invaded, it usually is the embryonic flowers into which the larvæ penetrate and produce the most conspicuous signs of the disease. Either before or just after differentiation of the terminal flower buds larvæ pierce the outer layers of cells, reaching the inner tissues in numbers usually larger than 2 and seldom more than 25. There they stimulate cell growth and gall production. Within each gall a cavity is formed, and in this the larvæ develop into sexually mature individuals, males and females, in about equal numbers. These then copulate, and before the galls are mature the females lay thousands of eggs. The latter then hatch, and the new larvæ go into dormancy as the galls mature.

ADULTS.

As soon as the larvæ have entered the host tissues they rapidly develop within the cavity of the growing gall into sexually mature females and males which, as shown at equal magnification in figures 5 and 6, are markedly different morphologically. They are of sufficient size to be plainly visible to the naked eye.

FEMALES.

Mature females vary considerably in length. The writer has found them in young green flower galls only 3.42 millimeters long, while Marcinowski's greatest measurement of length is 5.23 millimeters. Doubtless even wider variations than these occur. The average length seems to be about 4 millimeters. Their greatest width, though larger in proportion to their length than that of the larvæ, is also subject to great variations within the same individual. Young females may not measure more than 168 μ, while old females when well filled with eggs are much wider.

In general, the sexually differentiated females still remain spindle shaped, tapering gradually from the middle toward each end, but being somewhat thicker and fuller anteriorly (fig. 5). The head end terminates bluntly, while the tail end is distinctly pointed. Morphologically, the esophageal portion of the digestive system of the adult is not greatly different from that of the larva except as to size. Behind the posterior swelling of the esophagus, however, there are marked differences both in the intestine and the reproductive system of the adult as compared with those of the larva. In the young female the intestine, occuping a large part of the entire body cavity, becomes proportionately small as the reproductive system increases, so that in old individuals most of the body space is taken up by the egg-producing organ. The intestine is finally pressed closely against the body wall throughout its anterior half, while in the posterior portion it

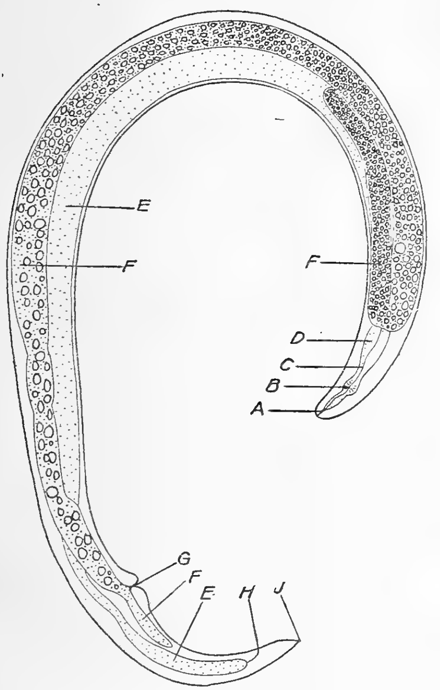


FIG. 5.—Lateral view of young female 1.95 mm. in length. Camera-lucida drawing. × 95. For an explanation of the letters A to J, see figure 6.

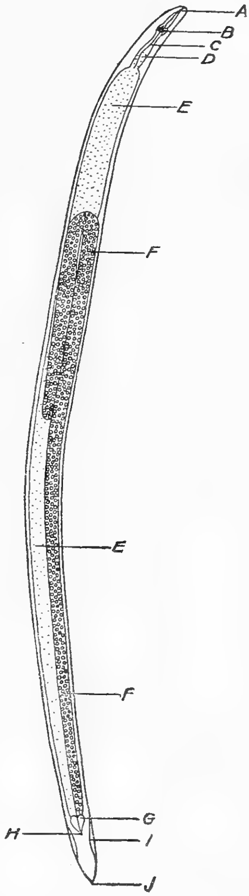


FIG. 6.—Ventral view of young male 1.36 mm. in length. Camera-lucida drawing magnified × 95. *A*, Spear; *B*, anterior esophageal bulb; *C*, esophageal canal; *D*, posterior esophageal bulb; *E*, digestive system; *F*, reproductive system; *G*, spicula in male and vulva in female; *H*, anus; *I*, bursa of male; *J*, tail.

gradually lessens in diameter and barely touches the wall. It contains at first granular bodies as well as liquids, and the entire contents appear yellowish brown in color. In old females, however, the intestine is almost colorless, transparent, and void of a large part of its granular food material.

The reproductive system, composed of two branches, opens at the vulva, which is situated about one-eighth to one twenty-seventh of the body length forward from the tail end. The fertile branch which extends in front of the vulva is at first glandular and saclike for a short distance. It then becomes smaller and continues as a fine tube of uniform diameter to near the middle of the organism. This tubelike portion, the uterus, is usually filled with many fertilized eggs in various stages of development, and in old females may contain hatched larvæ. The uterus expands into a vesicular-shaped portion, presumably the receptaculum seminis, where fertilization takes place, and the latter opens into the large end of the ovary, which contains mature ova. Usually the ovary folds twice, once near the anterior end of the intestine and again just forward of the middle of the animal, and terminates in a small blind end filled with rudimentary eggs. Back of the vulva there is a short, bag-shaped, glandular, sterile branch of the genital organs, the function of which is not understood.

As females mature they become tightly coiled and motionless, except for a slight motion of the head. Although still capable of being bent, they will, if straightened out and released, quickly recoil into a shape somewhat similar to that of a watch spring.

Egg laying begins soon after the galls are formed and continues for several weeks, during which time a single female may lay more than 2,000 eggs. As an average of about six or seven females are developed in each flower gall, the latter usually contains about 15,000 eggs or an equal number of larvæ into which the eggs soon develop. By actual count the writer has found 11,573 and 18,051 larvæ in what were selected as two medium-sized galls, while Dr. N. A. Cobb informs him that he has found as many as 90,000 in a very large gall. Like larvæ of the first stage, adult females as well as males are incapable of withstanding unfavorable conditions of temperature and moisture.

MALES.

As may be seen from figure 6, the adult male differs conspicuously from the female. It is much shorter, measuring from about 2 to 2.5 millimeters in length, or approximately one-half that of the female, and is more slender, its maximum width being from one-twentieth to one-thirtieth of the length. The anterior end is broader and not as rounded as in the female, and slightly in front of the pointed tail end it possesses a curved transparent wing, the bursa, with which females may be held. Near the center of this bursa is located the opening of both the intestine and the reproductive organs. The latter extends as a tube of about uniform diameter nearly up to the esophagus, folds back for a short distance, and terminates in a closed end. This tube is usually well filled with developing or mature spermatozoa, which with the aid of a copulating organ, the spicula, located near the sexual opening, may be ejected during coition. Unlike the intestine of the female and similar to that of the larvæ, the intestine of the male extends, largely undisturbed by the reproductive system, from the base of the esophagus nearly to the anus as a tube of uniform diameter.

The male is capable of movement during practically its entire life, retains its larval shape, and probably copulates only once. Sluggishly moving males are often found in galls which contain only the shapeless disorganized remains of females. As has been stated, males and females occur in about equal numbers.

EFFECT OF HIGH TEMPERATURES ON THE LARVÆ.

LARVÆ INSIDE OF THE GALLS.

In order to determine the maximum thermal death point of the larvæ, the writer has treated a large number of galls with hot water at various temperatures. The results of these tests are presented in Tables I and II. Galls soaked several hours or days in unheated tap water were used in obtaining the data given in Table I, while in Table II the data were obtained from treating the dry material. In all cases the same method was used in applying the hot-water tests. It consisted in submerging lots of two to six galls for the desired length of time in a large volume of water, the temperature of which did not vary during the course of the experiment more than 1 degree above or below that required, and usually varied less than half a degree in either direction. Following the treatment, each gall was placed in distilled water in a Syracuse watch glass, then carefully opened with sterilized instruments, and the larval contents microscopically examined repeatedly for several days afterward. In the first few experiments larvæ were discarded after having been under observation for one day subsequent to treatment, but it was soon discovered that some of the organisms showed signs of life at a later date, so in all succeeding experiments the larvæ were observed over a period of two to nine days. A total lack of movement of the larvæ in combination with the coagulation of their internal granular contents was taken as the criterion of death. The largest number of larvæ found to be living while they were under observation was roughly estimated in the percentage of the average number of individuals (about 1,500) contained in each gall. All the nematode galls used in these tests were from the same source, namely, a collection made on a farm near Union Mills, Va.

WATER-SOAKED GALLS.

A glance at the results presented in Table I, obtained from treating galls previously soaked, shows that the larvæ are only slightly affected by an immersion of as much as 15 minutes in water at 46°, 48°, and 50° C., respectively. They are completely killed, however, when exposed for 30 minutes or more in water heated to 50° C. Almost identical results secured by the writer after subjecting another parasitic nematode, *Heterodera radicicola*, to the same treatments suggest that other plant-attacking nematodes may respond similarly.

TABLE I.—*Effect of hot-water treatment on larvæ of the wheat nematode inclosed in wet galls.*

Lot.	Number of galls, each containing an average of more than 1,500 larvæ.	Hot-water treatment. Date, 1918.	Hot-water treatment. Temperature (° C.).	Hot-water treatment. Duration.	Extent of observation after treatment (days).	Larvæ active (per cent). In each gall at last examination. 1	2	3	4	5	6	Average— In each lot.	Average— In each treatment.
				Minutes.									
No. 15	6	Mar. 18	46	5	2	90	50	90	80	95	80	80.83	80.83
No. 14	5	...do	46	10	2	75	10	1	75	75	....	47.2	47.20
No. 13a	6	...do	46	15	2	90	2	10	90	60	100	58.66	58.66
No. 13	6	...do	48	5	2	90	90	90	85	60	80	82.5	82.50
No. 12	6	...do	48	10	2	90	90	90	90	50	85	82.5	82.50
No. 11a	6	...do	48	15	2	85	85	75	50	70	75	73.33	73.33
No. 9	6	...do	50	5	3	75	65	40	85	85	75	70.83	70.83
No. 8	6	...do	50	10	4	10	2	4	70	75	30	31.83	31.83
No. 17	6	Mar. 22	50	15	3	90	85	90	85	95	10	75.83	75.83
No. 18	6	...do	50	20	3	90	70	95	85	95	45	80	40.00
No. 2	6	Mar. 13	50	20	3	0	0	0	0	0	0	0	......
No. 19	6	Mar. 22	50	25	3	85	75	80	65	90	30	70.83	70.83
No. 23	5	Mar. 25	50	30	4	0	0	0	0	0	0	0	0
No. 24	5	...do	50	35	4	0	0	0	0	0	0	0	0
No. 25	2	...do	50	40	4	0	0	....	....	....	....	0	0
No. 26	5	...do	50	45	4	0	0	0	0	0	....	0	0
No. 11	6	Mar. 18	52	5	4	45	30	40	50	30	60	44.16	44.16
No. 10	6	...do	52	10	7	0	40	35	1	1	60	22.83	}18.1
No. 20	6	Mar. 22	52	10	4	0	0	.26	80	0	0	13.37	
No. 21	6	...do	52	15	4	0	0	.13	.5	.26	85	14.3	
No. 27	5	Mar. 25	52	15	5	0	0	.26	0	0	....	.51	}3.7
No. 40	6	Apr. 6	52	15	6	0	0	0	0	0	0	0	
No. 44	5	Apr. 16	52	15	6	0	0	0	0	0	0	0	
No. 22	6	Mar. 22	52	20	4	0	0	0	0	0	0	0	
No. 28	5	Mar. 25	52	20	4	0	0	0	0	0	....	0	}0
No. 39	6	Apr. 6	52	20	6	0	0	0	0	0	0	0	
No. 45	5	Apr. 16	52	20	6	0	0	0	0	0	....	0	
No. 29	3	Mar. 25	52	25	4	0	0	0	....	....	....	0	}0
No. 38	5	Apr. 6	52	25	6	0	0	0	0	0	0	0	
No. 1	6	Mar. 13	54	10	3	0	0	0	0	0	0	0	
No. 30	5	Mar. 25	54	10	5	0	0	0	0	.49	....	.08	}.02
No. 35	6	Apr. 6	54	10	6	0	0	0	0	0	0	0	
No. 41	5	Apr. 16	54	10	6	0	0	0	0	0	....	0	
No. 5	6	Mar. 13	54	15	3	0	0	0	0	0	0	0	
No. 31	5	Mar. 25	54	15	9	0	0	0	0	.2	....	.04	}.01
No. 36	6	Apr. 6	54	15	6	0	0	0	0	0	0	0	
No. 42	5	Apr. 16	54	15	6	0	0	0	0	0	....	0	
No. 37	6	Apr. 6	54	20	6	0	0	0	0	0	0	0	......
No. 43	5	Apr. 16	54	20	6	0	0	0	0	0	....	0	0
No. 34	5	Apr. 4	56	5	8	0	0	0	0	0	....	0	0
No. 32	5	...do	56	10	8	0	0	0	0	0	....	0	0
No. 33	5	...do	56	15	8	0	0	0	0	0	....	0	0
No. 3	6	Mar. 13	58	5	3	0	0	0	0	0	0	0	0
No. 4	6	...do	58	10	3	0	0	0	0	0	0	0	0
No. 6	6	...do	60	5	3	0	0	0	0	0	0	0	0
Check	6	...do	(1)	2	2	95	95	95	95	95	95	95	95
				Days.									
Do	6	Mar. 20	(1)	8	8	95	95	95	95	95	95	95	95

[1] Room temperature.

By increasing the temperature of the water to 52° C., all larvæ become motionless and lifeless after an exposure lasting 20 minutes. Exposures for a shorter time than this considerably reduced but did not entirely stop larval activity. In water at 54° C. the larvæ were practically all killed in 10 minutes, although there were six larvæ from one gall, or 0.02 per cent of the series, which at the end of this time showed faint signs of life. Likewise, when treated at the same temperature for 15 minutes, 0.01 per cent, or three larvæ, were found sluggishly moving. In both cases the fractional percentages of nematodes not killed are small enough to come within the expected limits of error, and in addition the faintly moving larvæ appeared so weakened as never to be able to parasitize the host. Thus, at least for all practicable purposes, these two treatments seem absolutely effective. No living larvæ were found in galls immersed longer than 15 minutes in water at 54° C., and the same was true if they were exposed to the liquid at 56°, 58°, and 60° C., respectively, for 5 minutes or more.

In the check experiments, 95 per cent of the unheated larvæ in the soaked and dry galls remained alive throughout the investigations.

It is both interesting and important to note that the hot-water treatments found effective for the nematode should so closely correspond to those which have been used successfully in controlling the loose smut of wheat caused by *Ustilago tritici*. Humphrey and Potter (17) recommend treating water-soaked wheat for 10 to 15 minutes in water heated to a temperature ranging from 52° to 57° C. (125° to 135° F.) to control this smut. Because of this fact, a single operation should suffice for both the nematode disease and the smut.

DRY GALLS.

Larvæ within dry unsoaked galls are much less affected by a given hot-water treatment than those contained in galls previously moistened throughout. No doubt this is due to the longer time required to raise the internal temperature of the dry gall to the thermal death point of the nematode. As shown in Table II, 29 per cent of the larvæ survived a hot-water treatment of 50° C. for 30 minutes, while 36, 24, and 55 per cent lived after immersions in water at 52° C. for 20 minutes, 54° for 10 minutes, and 56° for 5 minutes, respectively, all of which are treatments to which the larvæ in soaked galls succumbed. Only by increasing the time of exposure beyond that specified were the various temperatures entirely effective in killing the nematodes.

The figures obtained by the writer on the hot-water treatments differ materially from those of Davaine (11) and Marcinowski (22), who state that larvæ in galls are not killed by an immersion for 10 to 12 minutes in water at a temperature of 54° to 56° C. If the statements of these investigators, however, were supported by experimental data these were not presented, and furthermore, they failed to mention the important point as to whether they were treating dry galls or those that previously had been soaked in water.

TABLE II.—*Effect of hot-water treatment on larvæ of the wheat nematode inclosed in dry galls.*

Lot.	Number of galls, each containing an average of more than 1,500 larvæ.	Hot-water treatment.			Extent of observation after treatment (days).	Larvæ active (per cent).							
						In each gall at last examination.						Average—	
		Date, 1918.	Temperature (° C.).	Duration.		1	2	3	4	5	6	In each lot.	In each treatment.
				Minutes.									
No. 1	6	Mar. 13	50	10	2	0	0	0	15	5	0	3.3	3.3
No. 8	5	June 5	50	15	4	35	35	90	30	90	....	56	56
No. 2	6	Mar. 13	50	20	2	0	75	0	2	0	0	8.5	36.7
No. 9	5	June 5	50	20	4	40	40	90	75	80	....	65	
No. 24	5	June 17	50	30	3	60	.5	50	25	10	....	29	29
No. 25	5	...do	50	35	3	10	20	0	40	0	....	14	14
No. 26	5	...do	50	40	3	0	15	8	0	5	....	5.6	5.6
No. 27	5	...do	50	45	3	0	.06	15	20	0	....	7.1	7.1
No. 10	5	June 5	52	10	4	35	80	75	45	90	....	65	65
No. 11	5	...do	52	15	4	10	65	0	10	0	....	17	17
No. 12	5	...do	52	20	4	90	20	0	70	0	....	36	36
No. 28	5	June 17	52	25	4	1	20	15	55	40	....	26.2	26.2
No. 13	5	June 5	54	10	4	0	0	60	0	60	....	24	24
No. 5	6	Mar. 13	54	15	2	0	0	0	0	0	....	0	6.5
No. 14	5	June 5	54	15	4	0	0	35	10	20	....	13	
No. 15	5	...do	54	20	4	30	0	0	0	0	....	6	6
No. 16	5	...do	56	5	4	0	90	45	60	80	....	55	55
No. 17	5	...do	56	10	4	0	75	40	0	0	....	21	21
No. 18	5	...do	56	15	4	0	0	0	0	0	....	0	.1
No. 23	5	June 17	56	15	3	0	0	0	.2	0	....	.2	
No. 3	6	Mar. 13	58	5	2	0	5	0	75	0	30	18.6	29.8
No. 19	5	June 5	58	5	4	50	0	65	90	0	....	41	
No. 4	6	Mar. 13	58	10	2	0	80	.06	0	0	0	16	28.5
No. 20	5	June 5	58	10	4	50	0	65	90	0	....	41	
No. 6	6	Mar. 13	60	5	2	50	75	2	3	80	75	47.5	38.7
No. 21	5	June 5	60	5	4	70	0	80	0	0	....	30	
No. 22	5	...do	60	10	4	0	0	0	0	0	....	0	0
				Days.									
Check	6	Mar. 13	(1)	3	3	95	95	95	95	95	....	95	95
Do	5	June 5	(1)	4	4	95	95	95	95	95	....	95	

[1] Room temperature.

LARVÆ OUTSIDE OF THE GALLS.

Active larvæ liberated from galls were exposed to hot water in the following manner in order to ascertain their response to high temperatures. By means of a glass dropper about 300 nematode larvæ were transferred to diminutive bags of silk and then placed in a large receptacle of water of the desired temperature. After a specified time the bags were removed, the contents of each immediately emptied into distilled water in a Syracuse watch glass, and the larvæ examined microscopically on each of several days following the treatment. The highest percentage of nematodes found living at any one observation was recorded and is presented in Table III.

TABLE III.—*Effect of hot-water treatment on active larvæ of the wheat nematode taken from galls.*

Experiment.	Number of lots of larvæ of about 300 each.	Hot-water treatment.			Extent of observation (days).	Larvæ living (per cent).		
		Date.	Temperature (° C.).	Duration.		By lots. 1	By lots. 2	Average, by treatments.
				Minutes.				
No. 9	1	Mar. 27	48	3	4	85		85
No. 10	1	...do....	48	5	4	90		90
No. 11	1	...do....	48	6	4	50		50
No. 6	1	...do....	49	3	4	90		90
No. 7	1	...do....	49	6	4	50		50
No. 8	1	...do....	49	10	4	20		20
No. 3	1	...do....	50	3	4	75		75
No. 1–2	2	Mar. 26	50	5	4	50	60	
No. 27–28	2	Apr. 29	50	5	4	.6	4	19.7
No. 45–46	2	May 7	50	5	4	3	1.5	
No. 4	1	Mar. 27	50	6	4	15		15
No. 5	1	...do....	50	10	4	5		
No. 18	1	Apr. 15	50	10	6	0		
No. 29–30	2	Apr. 29	50	10	4	0	0	.8
No. 47–48	2	May 7	50	10	4	0	0	
No. 19	1	Apr. 15	50	15	6	0		
No. 31–32	2	Apr. 29	50	15	4	0	0	0
No. 49–50	2	May 7	50	15	4	0	0	
No. 20	1	Apr. 15	50	20	6	0		0
No. 12	1	Mar. 27	51	3	4	20		
No. 33–34	2	Apr. 30	51	3	4	2	4	5.8
No. 51–52	2	May 7	51	3	4	2	1	
No. 13	1	Mar. 27	51	6	4	1		
No. 21	1	Apr. 15	51	6	6	0		
No. 35–36	2	Apr. 30	51	6	4	2	1	.7
No. 53–54	2	May 7	51	6	4	0	0	
No. 14	1	Mar. 27	51	10	4	0		
No. 22	1	Apr. 15	51	10	6	0		
No. 37–38	2	Apr. 30	51	10	4	0	0	0
No. 55–56	2	May 7	51	10	4	0	0	
No. 23	1	Apr. 15	51	15	6	0		0
No. 15	1	Mar. 27	52	3	4	0		
No. 24	1	Apr. 15	52	3	6	0		
No. 39–40	2	Apr. 30	52	3	4	10	1	2.2
No. 57–58	2	May 7	52	3	4	1	.6	
No. 16	1	Mar. 27	52	6	4	0		
No. 25	1	Apr. 15	52	6	6	0		
No. 41–42	2	Apr. 30	52	6	4	.16	2	.3
No. 59–60	2	May 7	52	6	4	0	0	
No. 17	1	Mar. 27	52	10	4	0		
No. 26	1	Apr. 15	52	10	6	0		
No. 43–44	2	Apr. 30	52	10	4	0	0	0
No. 61–62	2	May 7	52	10	4	0	0	
				Days.				
Check	2	Mar. 27	(1)	4	4	95	95	95
		Apr. 29			6	95	95	
		May 7			6	95	95	

[1] Room temperature.

It is to be noted that neither the submersions at 48° nor 49° C. were of sufficient duration to kill all the larvæ, even though the number remaining alive was somewhat below that of the untreated lots held as a check. Treatments with water at 50° to 52° C. gave uniform results; that is, the percentage of larvæ surviving varied directly with the length of immersion. For example, at 50° C., 19.7, 15, and 0.8 per cent survived after exposures of 5, 6, and 10 minutes, respectively, while none lived where the exposure lasted for 15 minutes. Comparable results were obtained at higher temperatures, with all larvæ succumbing at 51° and 52° C. in 10 minutes. It is interesting to note that the minimum length of time required to kill all larvæ in these experiments at 50° and 52° C., namely, 15 and 10 minutes, respectively, is exactly half that consumed in accomplishing an identical result with the nematodes inclosed in galls which were soaked in water previous to treatment. Thus, the data as a whole in Table III show conclusively that the active parasites are much more sensitive to high temperatures outside of the protective galls than inside of them.

EFFECT OF CHEMICALS ON THE LARVÆ.

As adequate and dependable data regarding the response of larvæ to some of the chemicals more commonly used as sterilizing and disinfecting agents were not available, the writer has carried out a large number of experiments which were planned to obtain such data. In these experiments, as in those with hot water, both the free larvæ removed from galls and the protected larvæ inclosed in galls were treated. Experiments with the protected larvæ will be discussed first.

LARVÆ IN GALLS.

The method of procedure followed in subjecting the nematode galls to the chemicals and in determining the effect of the latter on the larvæ was essentially the same as that used in the hot-water investigations; that is, water-soaked galls were submerged in the solution for the desired length of time, then washed in water several times, and each opened in distilled water in a Syracuse watch glass. The larval contents were subsequently examined microscopically daily for several days to determine the effect of the treatment. The average number of larvæ from each lot of galls surviving the treatment, as well as other data, is recorded in Table IV.

By a study of Table IV it will be seen that unheated formaldehyde at strengths of 1:640, 1:320, 1:160, 1:100, and 1:80 produced no marked effect on the larvæ within two or four hours. Submerged in a 1:50 solution, however, for two hours only 2 per cent of the larvæ in the galls remained alive, and when kept in this same strength of the chemical for four hours none survived. Likewise, all larvæ were killed when the galls were treated in 4 per cent formaldehyde for two and four hours, respectively. A 1:320 strength of the chemical at a temperature of 50° and 52° C. killed less than half the larvæ when the galls were treated for one, two, and four minutes. It was thought that these hot solutions might be effective in eliminating the nematode, since Melhus (23) controlled oat smut by applying a 1:320 strength at temperatures of 45°, 50°, and 55° C. for one minute. In the galls kept in tap water for four days and used as a check on those treated with formaldehyde, 95 per cent of the nematodes were alive.

TABLE IV.—*Effect of formaldehyde, mercuric chlorid, copper sulphate, and sulphuric acid on nematode larvæ inclosed in water-soaked galls.*

Chemical and temperature.	Treatment. Strength.	Treatment. Exposure.	Treatment. Date, 1918.	Number of galls treated.	Average larvæ living in each lot (per cent).
		Hours.			
Formaldehyde: At room temperature (about 21° C.)	1: 640	2	Mar. 22	3	65
		4	...do....	3	90
	1: 320	2	...do....	3	73
		4	...do....	2	85
	1: 160	2	...do....	5	64
		4	...do....	3	90
	1: 100	2	Apr. 3	5	79
	1: 100	4	...do....	5	54
	1: 80	2	Mar. 22	3	72
		4	...do....	3	82
	1: 50	2	Apr. 3	5	2
	1: 50	4	...do....	5	0
	1: 25	2	...do....	5	0
		4	...do....	5	0
		Minutes.			
At 50° C.	1: 320	1	Apr. 17	5	59
		2	...do....	5	61
		4	...do....	5	70
At 52° C.	1: 320	1	...do....	5	80
		2	...do....	5	63
		4	...do....	5	54
		Days.			
At room temperature (check)	Tap water	4	Mar. 22	5	95
			Apr. 3	3	95
		Hours.			
Mercuric chlorid	1: 1,000	3	Oct. 19	3	63
		4	...do....	3	58
		5	...do....	3	28
		6	...do....	3	15
		7	June 4	6	0
		17	June 3	6	0
	2: 1,000	3	Oct. 19	2	57
		4	...do....	2	62
		5	...do....	2	37
		6	...do....	2	0
		7	June 4	6	0
		17	June 3	6	0
	4: 1,000	3	Oct. 19	3	40
		4	...do....	3	15
		5	...do....	3	0
		6	...do....	3	0
		7	June 4	6	0
		17	June 3	6	0
	10: 1,000	3	Oct. 19	3	46
		4	...do....	3	0
		5	...do....	3	0
		6	...do....	3	0
		7	June 4	6	0
		17	June 3	6	0
Copper sulphate	5 per cent	7	Apr. 4	5	78
		17	...do....	5	22
	10 per cent	7	...do....	5	10
		17	...do....	5	4
	15 per cent	7	...do....	5	4
		17	...do....	5	1
Sulphuric acid	½ per cent	7	...do....	5	74
		17	...do....	5	2
	1 per cent	7	...do....	5	5
		17	...do....	5	0
	1½ per cent	7	...do....	5	0
		17	...do....	5	0
		Days.			
Check	Tap water	5	...do....	5	95
			Oct. 19	5	90
			June 3	5	95

It appears, therefore, from a study of the results presented in Table IV that the nematode in protected galls does not readily succumb to formaldehyde and will survive treatments with this chemical which seriously impair the germination of the wheat.

In Table IV also are given the data secured by treating soaked galls with mercuric chlorid, copper sulphate, and sulphuric acid. As can be seen, these results are comparable to those obtained with formaldehyde, namely, that the nematode is strikingly resistant to the chemicals and that treatments with these chemicals which are not injurious to the wheat fail to kill the larvæ.

LARVÆ OUTSIDE OF THE GALLS.

The method of treating unprotected larvæ outside of the galls consisted in placing the actively moving nematodes, usually those removed from a single water-soaked gall, in the solution in a Syracuse watch glass. From the time the larvæ were put into the dish they were kept under continual microscopical observation for several hours, or a day, until after all signs of life had disappeared or until the treatment was discontinued. At the end of the experiment the percentage of larvæ living was noted, and this, with other data, is given in Table V.

TABLE V.—*Effect of various chemicals on unprotected larvæ of the wheat nematode outside of galls.*

Chemical.	Treatment. Strength.	Exposure.		Date.	Number of lots of larvæ.	Larvæ living (per cent).
		Hours.	*Minutes.*			
Formaldehyde	1: 240	4	55	May 31	3	0
		5	5	June 1	3	0
	1: 120	3	15	May 31	3	0
		3	5	June 1	3	0
	1: 100		36	May 14	2	0
			45	May 17	3	0
	1: 80		32	May 31	3	0
			25	June 1	3	0
	1: 50		46	May 14	2	0
			50	May 17	3	0
	1: 25		14	May 14	2	0
			17	May 17	3	0
Mercuric chlorid	1: 1,000	4	25	May 31	3	0
		4	35	June 1	3	0
	2: 1,000	2	27	May 31	3	0
		2	55	June 1	3	0
	4: 1,000	2	0	May 31	3	0
		2	30	June 1	3	0
	10:1,000	2	0	...do...	3	0
Copper sulphate	5 per cent	6	30	May 16	2	85
		8	35	June 1	3	5
		17	0	May 17	2	0
	10 per cent	6	15	May 16	3	60
		7	15	June 1	3	0
		17	0	May 17	3	0
	15 per cent	6	15	May 16	3	20
		7	45	June 1	3	0
		17	0	May 17	3	0
Sulphuric acid	½ per cent	3	20	...do...	3	60
		7	0	June 1	3	0
	1 per cent	3	5	May 17	3	40
		5	25	June 1	3	0
	1½ per cent	3	5	May 17	3	.001
		4	50	June 1	3	1
		Days.				
Check	Tap water	5		May 14	3	95
				May 31	3	95

A study of Table V shows that the larvæ are extremely resistant to the toxic action of the chemicals, living 4 hours and 55 minutes in formaldehyde of 1:240 strength and 4 hours and 25 minutes in mercuric chlorid of 1:1,000 strength. Submerged for 6½ hours in a 5 per cent solution of copper sulphate, 85 per cent of the larvæ remained alive; and immersion for 3⅓ hours in sulphuric acid of 0.5 per cent strength failed to kill 60 per cent of them. These few figures are sufficient to indicate the impracticability of using these chemicals for disinfecting seed.

By comparing the figures in Table IV with those in Table V it will be seen that a considerably longer time was required for the chemicals to kill the larvæ when they were inclosed in galls than when they were not.

OVERWINTERING OF THE PARASITES.

It is in the second larval stage that the organism lives from one season to the next. But just where most of these larvæ overwinter outside is an unsettled question about which there is no uniformity of opinion among the investigators who have studied the problem. Some of the earlier investigators, including Roffredi (30) and Henslow (16), were of the opinion that the larvæ overwintered in the protective galls which shattered out of the wheat heads at harvest time and dropped to the ground or else during the fall were sown in the soil along with the seed. According to these earlier workers the larvæ did not escape from the galls into the soil and infect the wheat plants until spring. On the other hand, Davaine (11) in 1857 concluded from his experiments that infection takes place in the fall when the nematodes are freed from the galls and that the larvæ overwinter in the young wheat plants. Since that time this view had been generally held by scientific workers until 1909, when Marcinowski (22) deduced from rather extensive experiments that most of the larvæ remain in the galls throughout the winter, although a few may escape at almost any time during the fall or winter and either live free in the soil or locate in the seedlings. It will thus be seen that there is no general agreement as to the manner in which the parasite passes the winter in the field.

The writer has tentatively concluded from preliminary observations on field experiments which are still under way that most of the larvæ get out of the galls in the fall and overwinter either in a free state in the soil or as an ectoparasite in the seedlings. Evidence supporting this view was found in January, 1919, when a large number of nematode-infected seedlings were observed in an experimental field plat. These infected seedlings occurred in rows of wheat which were grown from wheat seed planted October 11, 1918, in uninfested soil. Sown along with the seed was an equal volume of unopened nematode galls. It seems probable, therefore, from the large number of seedlings infected and from the many parasites found in some of the plants, that most of the larvæ must have escaped from the galls before January. It is not safe, however, to draw general conclusions from such limited observations, and the manner in which the larvæ live through the winter may depend upon the seasonal conditions occurring in the fall. Most likely the nematodes are liberated from the galls when favorable moisture and temperature conditions exist, regardless of whether this be in the fall, winter, or spring. That the larvæ, either within or without the gall, may withstand extreme cold is indicated by the laboratory experiments of Davaine (11), who subjected them without injury to a temperature of 15° to 18° C. below zero for five hours. The writer has kept them embedded in ice for several days and on reactivating them in water observed no injurious effect of the treatment. Indeed, the larvæ began their movements while the water was barely above the freezing point.

HOST PLANTS.

Investigators disagree as to the host range of *Tylenchus tritici*. Most of them, however, maintain that it is a highly specialized parasite normally attacking, to any appreciable extent, only wheat.

Both Roffredi (30) and Marcinowski (22) were able to produce only small, imperfect flower galls of barley (*Hordeum vulgare*) and rye (*Secale cereale*) by artificial inoculation with larvæ. In a similar manner more pronounced infection was secured in spelt (*Triticum spelta*), although in this plant the number and size of the galls fell much below that of wheat (*Triticum vulgare*) subjected to like treatment. Also, under natural conditions, spelt is reported to have been slightly diseased. Henslow (16), without adducing convincing evidence, states that he obtained with difficulty a slight infection of oats (*Avena sativa*), rye, and barley.

During the season of 1918–19, the writer, in cooperation with A. G. Johnson and R. W. Leukel (9), induced an abundant infection of emmer (*Triticum dicoccum*), rye, and spelt, and a slight infection of oats. These crops were grown in a previously uninfested field and were inoculated by sowing in certain rows seed mixed with nematode-containing galls. In other rows seed infested with free nematodes was planted.

In the case of rye, spelt, and emmer, flower galls of about the size of those produced on wheat occurred on numerous spikes of these plants. In oats only a few small flower galls were found in a limited number of plants. Similar experiments on barley gave only negative results.

Thus, from the rather limited data available on the subject it is evident that the nematode may parasitize cereal grasses other than wheat, although apparently not to so great a degree. Further careful observations in the field and more adequate cross-inoculation experiments are necessary, however, in order definitely to determine the relation of the nematode to these cereals.

On many wild grasses, flower galls due to species of nematodes closely related to and by many believed to be identical with *Tylenchus tritici* have been found by both European and American observers. Bessey (4) in 1905, for example, reported that he had found such galls in grasses of the genera Chaetochloa, Agropyron, Elymus, Calamagrostis, and Trisetum collected in Texas, Oregon, and Alaska, but was unable to determine whether any of them were induced by an eelworm identical with the wheat nematode. Some investigators have given the causal organism occurring on the various grasses specific names, such as *Tylenchus agrostidis*, *T. graminearum*, and *T. phalaridis*, depending largely upon the host attacked, and sometimes in the brief inadequate description of these parasites the writers have pointed out minor differences between them and *Tylenchus tritici*. On morphological grounds alone these described differences are not sufficient to warrant separating them from the wheat nematode, and for this reason Dujardin (13), Diesing (12), and Bastian (2) in their helminthological monographs have considered them identical with *Tylenchus tritici*. Whether the gall-producing nematodes discovered on different grasses are physiologically alike in parasitism can, of course, be determined only by cross-inoculation experiments, a thing which the above-mentioned investigators apparently did not attempt. Marcinowski (22), however, in an experiment covering two years, failed to induce flower infection of many grasses with *Tylenchus tritici*. Each plant during the first year was inoculated with the larvæ of several hundred wheat galls and during the next year was again treated with the larval content of about 300 galls. The grasses used in the experiment were, for the most part, those on which galls had been reported. They are as follows:

Agrostis capillaris, A. stolonifera, A. canina.
Bromus erectus, B. pratensis, B. secalinus.
Alopecurus geniculatus.
Festuca ovina, F. pratensis, F. vulgaris.
Holcus lanatus.
Poa annua, P. pratensis.
Phleum bohmeri, P. pratense.

Although suspicious symptoms appeared in the leaves during the second year on *Festuca vulgaris*, *Poa annua*, and *Alopecurus geniculatus*, not a single gall was found on any of these hosts, and the fruit matured normally.

In examining many of the common grasses, especially *Bromus secalinus* and *Dactylis glomerata*, growing in and near severely diseased fields of wheat in Virginia, the writer has been unable to find nematode galls of either the flower or leaf. The evidence at hand, therefore, seems to indicate that the nematode on wheat is not identical with forms producing flower galls on wild grasses.

Not infrequently nematode galls located only on the leaves of grasses have been reported. Some of these are caused by organisms morphologically similar to and by some investigators also thought to be identical with *Tylenchus tritici*. The writer has found such leaf infections particularly abundant on *Calamagrostis canadensis* in Wisconsin, but these are caused by a species of Tylenchus different morphologically from the wheat nematode. In general appearance they resemble somewhat the uredinia of certain rusts, for which they have been mistaken. As a rule, they are small, yellow, ellipsoid swellings, about 5 mm. long, 2 mm. wide, and 2 mm. thick, which involve the entire thickness of the leaf at the affected point, causing it to protrude slightly from the upper and lower surfaces. Their long axis extends in a direction parallel to the midrib, and they may occur on any portion of the leaf. Grasses so affected have been observed many times in both America and Europe. As in the case of the nematodes causing flower galls on various grasses, it is not possible, on account of the brevity of descriptions, to determine positively whether all the nematodes in the leaf galls of grasses differ from *Tylenchus tritici*. On the whole,, it seems rather unlikely that any of them are identical with the wheat organism, since the latter is primarily a parasite of the inflorescence and only occasionally produces leaf galls.

An interesting and important question is whether identical organisms are responsible for the leaf and the flower galls of the wild grasses, on some of which both types of attack occur. In the case of wheat, the writer has shown that the two kinds of galls may be induced by *Tylenchus tritici*. Davaine (11) obtained similar results and Kieffer (20) also noted definite leaf swellings which contained a species of Tylenchus very likely identical with *T. tritici*, but Marcinowski (22) was unable to find leaf galls on wheat.

From what has been said it is evident that considerable investigation is needed to extend our knowledge of the relation between *Tylenchus tritici* and other nematodes occurring on grasses.

METHODS OF SPREADING THE PARASITES.

Only in its second larval stage does the parasite constitute a source of new infection. All other stages of the life cycle are more or less transitory, unable to withstand unfavorable conditions, and unable to live or develop for any appreciable time outside the host plant.

It is evident that the larvæ are most frequently introduced into new localities while contained in the galls. The latter may be transported along with seed wheat in which they are mixed, or in soil, or by many other means. If conditions are unfavorable for the larvæ to escape from these galls, the parasite is able to remain in a lethargic dried state for many years and afterwards to produce the disease. The organism may also be transferred long distances outside of the protective galls, in which case it probably could not remain alive and active for more than one year unless a host plant were found. In this free state the larvæ are most likely to be carried in soil, which is practically the only place where they normally occur outside the host. Although the spreading of free larvæ may take place, it is, of course, almost entirely by means of those contained in galls that the organism reaches widely separated areas. In the latter condition it has been repeatedly introduced into this country with importations of seed wheat. In all probability such introductions would have been entirely prevented or long delayed if careful inspection of all shipments had been made. In the future every precaution should be taken to prevent its further importation.

Once introduced into a locality the larvæ are capable of traveling by their own movements only very limited distances in the soil. Haberlandt (15) states that he obtained infection in seedlings which were growing in the ground 20 cm. distant from an unopened gall. The writer has found abundant infection in seedlings growing 30 cm. away from unopened galls which were buried a few inches below the surface of the ground. When it is considered that this movement must have taken place within a short time, probably less than a month, the rate of travel for so small an animal is fairly rapid. Probably during the course of a growing season, in which infection may take place at any time if young plants are available, the organism might be able to cover several feet or even a few yards. It is, however, not through their own efforts that these larvæ mainly are spread. Many other means are at their disposal. Either within or without the galls, they may be distributed by running water or water resulting from heavy rains. They will not drown after months of submersion, and as drying for a long period does not kill them they may be carried alive in small particles of desiccated soil in various ways, such as on the feet of men and animals, and by agricultural implements. Fortunately, there usually is but little tramping over fields while they contain growing wheat, so that this is an unimportant means of spreading the parasite except when no crop is present.

Of course, the chief manner of spreading the parasite within a locality is by the sowing of seed wheat which is mixed with nematode galls. As pointed out later, it is possible to free the seed by a simple method, yet it is the part of wisdom to sow clean seed which has been grown in uninfected areas.

METHODS OF CONTROL.

Fortunately, the nematode disease appears to lend itself fairly readily to control measures. At least this has been the experience of European agriculturists, and there seems to be no reason why the malady should not respond to proper combative methods in this country. Indeed, the measures employed are so obvious and apparently so effective that very little attention has been given to this feature of the disease by research men, no doubt for the reasons given. Successful methods of control are given below, based on the etiology of the disease as presented and on limited field observations by the writer and investigators in England and continental Europe.

CLEAN SEED.

To prevent the occurrence of the malady it is absolutely essential that clean wheat unmixed with nematode galls be secured for seed purposes. The disease may be detected most readily at harvest time or after thrashing. If dark, hard galls, containing a white mass of nematodes, are found in the wheat, such grain should not be used for seed unless no other is available. Instead, a supply grown in localities in which the disease does not occur should be obtained.

However, if clean seed is not obtainable, the nematode galls may be separated from the sound wheat by the so-called salt-brine method devised by Johnson and Vaughn (18) for removing ergot from rye. Essentially it consists in pouring the infected seed slowly into a water solution containing 20 per cent of common salt (NaCl) and at the same time stirring vigorously. Because of their lower specific gravity, the nematode galls, light kernels, smutted grains, the seeds of some weeds and grasses, and other foreign material will float, while the sound grain will sink. After removing the galls and other floating matter from the surface of the solution, pour off the latter and rinse the grain in water immediately. After being freed from nematode galls the grain should be spread out to dry, after which it is ready for planting. With Dr. A. G. Johnson, the writer has successfully employed this salt-brine method, separating and removing every gall from several bushels of wheat which contained more than 50 per cent of the injurious galls. The method is not only entirely effective and inexpensive, but also readily adaptable for operations involving small or large quantities of grain. The germinating quality of the grain is not impaired by the treatment.

The writer has also separated nematode galls from small quantities of diseased wheat by another method, which requires considerable care and effort for its successful execution. It is carried out by releasing water under pressure at the bottom of a receptacle which contains the infected wheat and stirring and roiling vigorously at the same time. If the water is released through a hollow rod attached to a hose the rod may also be used in stirring the grain. With such treatment the nematode galls and other light material will rise to the surface and may be easily removed. Whether this water method would be effective for use where large quantities of grain are to be separated has not been determined.

In removing the galls by either of these means there is little likelihood that seed so cleansed will bear any living larvæ on the surfaces of the kernels. Only rarely do the larvæ escape from galls which are held under the usual storage conditions, and any that might escape would most likely be killed by the usual rubbing together of the kernels as the grain is handled. On drying out, the larvæ become stiff and brittle and are very easily broken. However, in order to eliminate the possibility of transmitting any source of infection along with the sound kernels the cleaned seed can be treated with hot water at a temperature of 51° to 52° C. for 10 minutes, a treatment which the writer has found to kill unprotected larvæ. According to Humphrey and Potter (17) this treatment is also sufficient for controlling loose smut (*Ustilago tritici*). If the hot-water bath is to be given, it should be applied directly after the wheat has been separated from the galls.

Although the methods just described would seem to obviate the necessity of any other means of disinfecting the grain, another means of accomplishing equally good results is available. It consists of soaking the gall-mixed seed for about an hour in unheated water and immediately immersing it for 20 or more minutes in water held at a temperature of 52° C. Equally effective has been found either an immersion of the soaked seed for 15 minutes in water maintained at 54°, or for 10 minutes at 56° C. The writer has never been able to find living nematodes within galls given any of these treatments, although these observations are apparently at variance with those of Marcinowski (22), and Davaine (11), who report that they were unable to kill the organism by immersing the galls in water at a temperature of 54° to 56° C. for 10 to 12 minutes. Doubtless they did not previously soak the infected seed. This supposition would account for the difference in results, as it takes a much longer time to raise the internal temperature of dry galls or seeds than that of those which are wet.

The various chemicals ordinarily used for disinfecting purposes, such as formaldehyde, mercuric chlorid, and copper sulphate, failed to kill the nematodes when used in strengths which did not injure the seed.

CROP ROTATION.

Crop rotation, as well as the use of nematode-free seed, is essential in controlling the disease, as the indications are that the parasite may live in the protective gall for one or more years in soil in which no congenial host grows, and at the end of that time constitute a source of infection. If infested land be planted for two or preferably for three consecutive years to nonsusceptible crops, most or all of the nematodes will be eliminated. Although these nematodes are capable of remaining alive, but inactive, in a dried, stiffened state for a number of years, under the usual field conditions the temperature and moisture are such that they become active during the warmer months, and in this motile stage they will starve in less than a year provided no susceptible plant is available. Almost all of the active larvæ will have starved in the soil during the first year after a diseased crop has been harvested, but it is advisable not to plant a susceptible crop on infested land until after two or more years. In England, where a 2 to 3 year rotation of crops, including wheat, is now commonly practiced, Ormerod (27) reports that no difficulty in controlling the disease has been met with if uninfected seed wheat is sown. Marcinowski (22) made a similar report of conditions in Germany.

Until our knowledge concerning the range of the host plants of *Tylenchus tritici* is more complete, it is highly inadvisable to grow not only any variety of wheat, oats, rye, emmer, or spelt but also any of the closely related grasses on land that is to be freed from nematodes. So far as known, all strains or varieties of wheat are equally susceptible, none having been reported as resistant. All wild grasses, especially those on which flower galls caused by nematodes have been found, should be scrupulously kept off the land, as some of them may be susceptible to the wheat nematode. These grasses, as well as weeds, may be more easily kept down if the rotation crops are planted in rows so as to permit clean cultivation. As there are no plants outside of the grass family on which *Tylenchus tritici* has been reported, several presumably immune crops exist which can be used in rotations designed to control the disease. Every precaution against reinfesting the soil should be taken if success in controlling the nematodes by crop rotation is to be obtained. Spreading the pest by those means already pointed out should be prevented.

Other methods of controlling the parasite have been proposed, but because of their inefficiency or impracticability they have not been adopted. Kühn's (21) catch-crop method, once thought to be a practicable means of controlling the sugar-beet nematode (*Heterodera schachtii*) has been proposed. It consists of growing a susceptible plant, in this case wheat, on the land, allowing it to become well infected, and then destroying the young plants at the proper time to catch the largest number of nematodes. Then by removing the crop from the land many of the parasites are eliminated. The method is ineffective because only a portion of the nematodes free in the soil enter the seedlings, and it is also impracticable because of the cost involved. Deep plowing is a more successful means of reducing the disease, but this by itself is not adequate to eliminate the nematodes. The deeper the larvæ are turned under the soil below a depth of a few centimeters, the less opportunity they have for reaching and infecting plants. Marcinowski (22) obtained a higher percentage of infection when the nematodes were placed 3 centimeters below the surface of the soil than at any other depth, and only a small number were able to reach the wheat seedlings buried at a depth of 30 centimeters.

SUMMARY.

A serious disease of wheat known in Europe since 1743 and due to the nematode *Tylenchus tritici* (Steinbuch) Bastian has been recently found causing considerable damage in certain parts of the United States, particularly in Virginia.

Reports in the literature and an examination of specimens received from various foreign countries show that the malady is almost world-wide in distribution, having been discovered in all continents except Africa. Within the United States it is known to occur at present in California, Virginia, West Virginia, Maryland, and Georgia, and other States also may be found to be infested.

Samples of harvested wheat collected in Virginia contained from less than 1 per cent to more than 50 per cent of diseased kernels by count, and as much as 40 per cent damage by it to some fields of wheat in the same State has been observed.

On seedlings the disease usually causes a decided wrinkling and rolling or distortion of the young leaves, which, if severely attacked, turn yellow, wilt, and die. Occasionally such leaves have one or more small light-colored galls, which may be located on any portion of the leaf and contain the causal organism. Roots are not directly affected, nor do the stems of infected plants near the surface of the ground become swollen, as in the case of tulip-root, another disease of wheat, caused by the nematode *Tylenchus dipsaci*, which infects stems and crowns. It is on the maturing spikes that the malady produces the most conspicuous symptoms. As a rule, infected heads retain their green color longer than normal spikes. They are reduced in length and have their glumes spread out at greater angles than uninfected spikes. In place of normal kernels the glumes contain dark, hard galls, which are shorter and frequently thicker than wheat grains and which may be seen sometimes partly exposed in diseased spikes. Because of a general similarity, these galls often have been mistaken for the seed of cockle (*Agrostemma githago*), a weed which occurs commonly in wheat fields, for kernels affected by stinking smut due to *Tilletia tritici*, and for bin-burnt wheat caused by overheating the stored grain.

The disease is caused by a minute nematode, *Tylenchus tritici* (Steinbuch) Bastian, the larval stage of which in great numbers may be seen with the unaided eye when a gall is teased apart in water. These larvæ in mass appear milky white in color. Individually they are threadlike animals, nearly 1 millimeter in length and capable of an eellike movement. Under favorable conditions of moisture and temperature they escape from the galls which have fallen to the ground or have been sown along with wheat seed, and by their own movement reach the young seedlings. They finally become located between the leaf sheaths near the terminal stem bud and in this region are passively elevated to the inflorescence. Occasionally they penetrate the leaves and induce small swellings, but usually they enter only the embryonic flowers, which develop into galls instead of kernels. In these places the larvæ, after several metamorphoses, develop into about equal numbers of male and female adults, the former about 2 mm. in length and the latter from 3 to 5 mm. long. Each female may lay more than 2,000 eggs. Measuring approximately 37 μ wide by 85 μ long, these eggs are elongate, ellipsoidal, granular bodies, which in a short time after oviposition develop into larvæ and in this manner complete the life history of the organism. At the maturity of the plant the larvæ within the gall become inactive, dried, and motionless, in which lethargic condition they can remain alive for many years.

The larvæ inclosed in galls were killed by an immersion in water at temperatures of 50°, 52°, 54°, and 56° C. for 30, 20, 10, and 5 minutes, respectively, provided the galls were thoroughly moistened before the treatment. Much longer immersions at the same temperatures are necessary to kill them if the galls are dry when treated. Free from the protective gall, the larvæ succumb to temperatures of 50° and 52° C. in 15 and 10 minutes, respectively; that is, in half the time required to kill them within the galls. Larvæ either inside or outside the protective gall are highly resistant to the toxic action of formaldehyde, mercuric chlorid, copper sulphate, and sulphuric acid. They live after long submersion in concentrations of these chemicals, which in a short time are injurious to seed wheat.

The nematode appears to be primarily a parasite of wheat. To a less extent it parasitizes rye, oats, spelt, and emmer, and it has been reported on barley.

The malady is most commonly spread by means of seed wheat containing nematode galls. It may be distributed in various other ways, such as by the feet of men and animals and by agricultural implements to which dirt containing viable larvæ may cling. Surface water resulting from rains often transports the parasite from an infested to an uninfested field.

The disease may be controlled by the use of nematode-free seed in combination with the employment of a 2 to 3 year crop rotation and the application of proper sanitary precautions. Uninfected wheat for planting should be secured, if possible, from localities where the disease does not occur. Nematode-free seed, however, may be obtained from diseased grain by floating off the galls in a 20 per cent salt solution and then treating the remaining wheat with water at a temperature of 50° to 52° C. for 10 minutes. Diseased seed can also be freed from nematodes without removing the galls by immersing them in water at a temperature of 54° to 56° C. for 10 to 12 minutes. By keeping wheat off infested land for two or, better, for three years, all or most of the nematodes will have starved, so that the subsequent wheat crop will not be appreciably damaged. Every precaution should be taken to prevent the reintroduction of nematodes to land which is being rotated to control the disease.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 843

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER June 7, 1920

THE BEAN LADYBIRD.

By F. H. CHITTENDEN, *Entomologist in Charge*, and H. O. MARSH, *Entomological Assistant, Truck-Crop Insect Investigations.*

With a report on "The Bean Ladybird in Colorado, in 1919."

By A. C. MALLORY, *Scientific Assistant.*

CONTENTS.

INTRODUCTION.

In the semiarid region of the Southwest, where an immense acreage of beans is grown annually, a destructive insect known as the bean ladybird, bean beetle, "bean bug," and spotted bean beetle[1] does great injury. Indeed, it is to the bean crop what the Colorado potato beetle is to the potato, a pest of the highest importance in the region which it inhabits.

The beetle devours all parts of the bean plant—leaves, flowers, and growing pods. Its main food supply, however, is the leaves, through which it cuts irregular holes (Pl. I; III; IV, fig. 1). Its injuries,

[1] *Epilachna corrupta* Muls.; order Coleoptera, family Coccinellidae.

NOTE.—This insect was under the observation of the junior author (who died September 10, 1918), from 1914 to 1917. The life-history investigations were conducted in an open-air insectary at Rocky Ford, Colo.; and some field operations were conducted also at Pueblo, Fort Collins, and Colorado Springs, Colo., and at Maxwell and French, N. Mex.

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so far as is known, are practically confined to beans, and no variety seems to be exempt from injurious attack. This insect has been observed feeding on various forms of the kidney bean (*Phaseolus vulgaris* et al.), including string, pole, navy, and tepary or Mexican, and on the lima bean (*Ph. lunatus*). Of these string beans are favorites. On one occasion the soy bean (*Soja hispida*) was attacked. The beetles, unlike those of the bean leaf-beetle (*Cerotoma trifurcata* Forst.), show no tendency to injure very young plants and the larvæ work on the lower surface of the leaves, skeletonizing large, irregular areas without cutting the epidermis or upper skin. (Pl. II, III.)

It is fortunate that its field of operations is limited, both as regards the crop plants affected and the territory over which it ranges. It has been estimated that it does an annual damage in New Mexico varying from 5 to 100 per cent of the crop, the average loss being conservatively placed at 10 per cent.

This species is remarkable in that it is one of two species of ladybirds occurring in the United States[1] which feed exclusively on vegetation, the other forms of the ladybird family being predacious and subsisting largely on plant-lice, or aphids, and the eggs of insects.

SYNONYMY.

The bean ladybird was described by Mulsant in 1850 (1, p. 815)[2] under the name by which it is known in economic literature, *Epilachna corrupta.* In the original description in which this name appears, printed under No. 90, *E. varivestis* is also described as No. 91, yet Crotch (3, p. 62), followed by Gorham (8, p. 242), recognized the latter as the proper name for the species, and relegated *corrupta* to synonymy, in which case the strict law of priority has not been followed. This species has evidently been described under at least a half dozen names, but as there is no means of deciding positively the exact term to apply to the species under consideration, *Epilachna corrupta* is here used to avoid further confusion, although *E. varipes* Muls. was described first and is acknowledged by Crotch and Gorham to be the same species. The name used by Bland (2), *E. maculiventris*, described in 1864 from the Rocky Mountain region of Colorado, undoubtedly applies to this species and naturally falls into synonymy.

DESCRIPTION.

THE ADULT.

The adult (fig. 1, *b*) is a robust beetle, oval in outline, and about one-fourth of an inch in length by about one-fifth of an inch in

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[1] The other is known as the squash ladybird (*Epilachna borealis* Fab.).

[2] Reference is made by figures in parentheses to "Literature cited," p. 20.

width. The color of the newly developed adult is yellow, gradually darkening with age to a grayish brown. Each elytron or wing-cover is marked with eight small black spots of variable size.

Technical descriptions of the genus and species follow:

GENUS EPILACHNA.

Large, pubescent species related to Chilocorus. Sides of prothorax only slightly curved and broadly explanate; those of elytra rather strongly reflexed; epipleuræ horizontal, broadly concave, not distinctly extended to sutural apex. Metasternal and ventral lines well-defined, legs moderately retractile; femora not deeply sulcate beneath, tibiæ with an acute external edge, and shallow groove for reception of tarsi; claws cleft, with lower cusp nearly as long as upper.

EPILACHNA CORRUPTA MULS.

Form oblong, more narrowly oval than *borealis* and distinctly smaller, dull in luster, densely pubescent, and very closely, unequally punctate; color grayish brown; head and pronotum without spots. Each elytron ornamented with

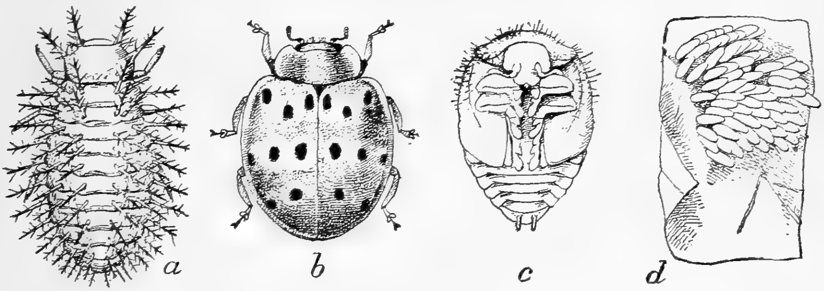

FIG. 1.—The bean ladybird (*Epilachna corrupta*): *a*, Larva; *b*, beetle; *c*, pupa; *d*, egg mass. About three times natural size.

eight spots or dots of varying size in three rows; three small sub-basal spots in a broken row, median less basal; three in a transverse subparallel row just before the middle, usually larger than sub-basal, median usually a little larger, and two near apical fourth, placed near inner fourth and outer third. Lower surface darker or concolorous with legs, which are pale throughout.

Length 6.5–7.8 mm.; width 4.8–5.4 mm.

The so-considered Mexican variety, *E. varipes* Muls., differs mainly from the species under discussion as it occurs north of Mexico in having the two subapical spots united or coalescing, forming an arcuate fascia. All spots are also larger and surrounded by a lighter aureole. The typical *varivestis*, as figured by Gorham, shows these aureoles, but they are less pronounced in many specimens from the United States.

Specimens occasionally occur of a more or less pronounced buff color, but these usually are not fully colored, being more or less immature when killed for mounting.

THE EGG.

The egg is dull pale yellow, elliptical in outline, approximately twice as long as wide, a little larger at the base or attached end than at the apex. The surface is strongly sculptured. The length of the egg is 1.25 mm.; the width 0.6 mm.

The eggs are deposited on end on the lower surface of the bean leaves (Pl. IV, fig. 1) in irregular masses, varying from half a dozen to about 75, with an average of between 40 and 50. (See fig. 1, *d.*)

THE LARVA.

The larva is yellow and the body is armed with long, formidable, strongly branched spines, darker at the tips. When full grown these spines, although somewhat irregular, are arranged in rows both longitudinally and transversely, as shown in the accompanying illustration (fig. 1, *a*). The head is moderately prominent, as are the mandibles and other mouth-parts, which with the eyes are darker than the other parts. The legs are rather long and stout and the anal segment is obtusely and roundedly produced. The newly hatched larva measures about one-sixteenth of an inch in length and the full-grown larva about five-sixteenths of an inch. Descriptions of the larval stages, as given by Merrill (21), follow:

First Stage. When the yellowish larva first frees itself from the egg the spines are closely appressed. As the chitin dries, the spines become erect and are seen to be branched at and near the tip. Later the tips of the branches become darker. The larva is about 1.3 mm. long by .6 mm. wide. The body tapers sharply in the abdominal region and is recurved downward. There is a row of four spines across the front of the rather pronounced pro-thorax. On the rest of the body there are six longitudinal dorso-lateral rows, the spines of the outside rows being very small and very few. * * *

Second Stage. After the first moult the larva is 2 mm. long and the tip of the abdomen is slightly more curved than in the first stage. The spines are longer and more branched. The dark tips are not so pronounced. The rows of spines are the same in number but more distinct. * * *

Third Stage. After the second moult the larva is 4 mm. long. The spines are longer, more branched from the sides, and dark tipped. The rows are now easily seen. In this stage the larva seems to be rather humpbacked, the highest and widest portion of the body being about the middle portion. The abdomen tapers sharply, the anterior end slightly, only. * * *

Fourth Stage. At the beginning of the fourth stage the larva is 5.4 mm. long and it increases to nearly 1 cm. in length before the fourth moult. The chief difference between the larva in this stage and in the last is in the size.

THE PUPA.

The pupa (fig. 1, *c;* Pl. V) is ovate in outline, and approximately the size of the adult. It is yellow with brown markings. Anteriorly it is roundedly subtruncate and posteriorly tapers strongly toward the apex. The surface is sparsely beset with bristle-like setæ and long hairs. The head is folded down in front over the thorax and the posterior legs reach below the wing-sheaths. The apex terminates in two elongated processes, conical at the base and black at the extreme tips. The larval exuviæ are pushed down and form a protection for the last abdominal third of the body. (Pl. VI.) Length 7–7.5 mm.; width 4–4.5 mm.

DISTRIBUTION.

The bean ladybird occurs in the States of New Mexico, Arizona, Colorado, and Texas. In the last mentioned State it is restricted to localities in the western part. It is also said to occur in Kansas and Arkansas but not as a pest. There is a single record of a beetle, presumably a "chance find," having been taken at Ogden, Utah, but it is not positively known that the species breeds in that State.

The bean ladybird, as has been stated, is to the bean industry in the West what the Colorado potato beetle is to the potato crop in the East, and its origin is obviously the same—Mexico, where it is widely distributed. It is also found throughout Central America. It has been observed at elevations of from 3,000 to 7,000 feet above sea level in New Mexico, and of about 4,000 to approximately 5,000 feet in Colorado.

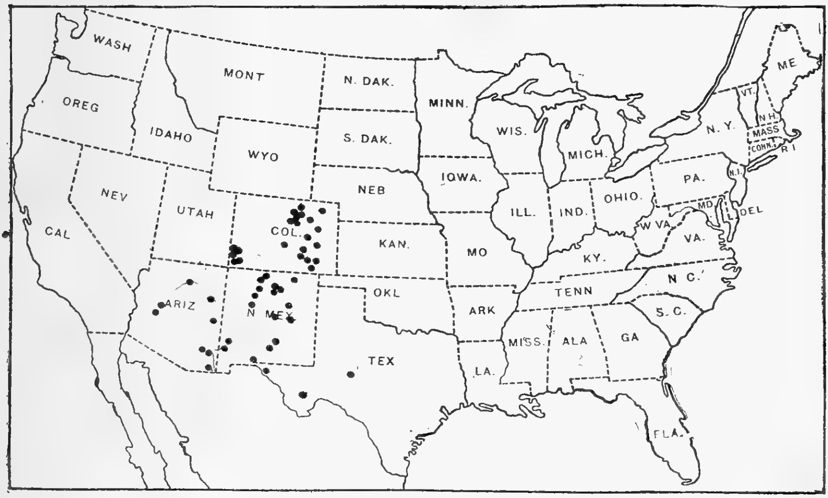

FIG. 2.—Map showing known distribution of the bean ladybird in the United States, June 1, 1919.

According to the observations of Dr. C. P. Gillette, State entomologist of Colorado, the species inhabits the foothills of the Rocky Mountains, seldom straying far out on the plains, with the exception of down the Arkansas Valley in Colorado. Further details in regard to its distribution in that State are furnished on page 13.

The known distribution of the bean ladybird in the United States is indicated in figure 2.

DANGER OF FUTURE SPREAD.

In regard to the future distribution of this pest it must again be compared with the Colorado potato beetle, first because of its obviously similar origin. It may have been introduced at an even earlier date than the latter, since the cliff dwellers in the region which the beetle inhabits in the United States included tepary beans in their dietary. From an economic standpoint it is a potential pest of the type of the Colorado potato beetle and the boll weevil and it is singular that it has never migrated to any noticeable extent as have those pests, since it is probably capable of extended flights. One reason that may be assigned for this is its practical limitation to a single food plant, while the potato-feeding insect infests virtually all of the Solanaceae, including the weeds, and is capable of breeding continuously on all species of Solanum and probably on other genera. There is no reason to suppose that this insect may not by flight increase its present range materially some time, although not necessarily in the near future. Its further dissemination, however, would doubtless be slow and never as rapid as in the case of the comparatively fleet-winged and more adaptable Colorado potato beetle. The reasons, then, for its failure to have become more widely distributed are: Its limitation to a single food plant and its probable incapacity for protracted flight with the wind. Moreover, it is probably not capable of inhabiting such varied climates as is the Colorado potato beetle, a species which seems to have no respect for life zones but which thrives equally well from subtropical southern Texas to boreal Manitoba.

In the case of the Colorado potato beetle it can not as yet be definitely stated, as some authors have assumed, that it breeds wherever potatoes are grown, but it is perfectly capable of doing so, and it may be that in the course of time, many years undoubtedly, the bean ladybird will be distributed wherever its food plant is cultivated.[1]

Another factor which strengthens the belief that the bean ladybird will, in the course of time, become more widely disseminated is its very close relationship, both structurally and biologically, to the squash ladybird (*Epilachna borealis* Fab.), which ranges from South America northward through Central America, Mexico, and the Antilles, along the Mexican and Atlantic seaboard States to Maine and Canada. Obviously the squash-feeding species has a similar tropical origin, beginning farther southward and extending much farther northward. Instead of progressing straight northward it has followed more nearly the coastal lines and has a totally different distribution in the United States, being somewhat restricted to the East[2] just as the bean ladybird is restricted to the Middle West.

The present distribution of this species as outlined in the map would indicate that we may expect its establishment some time in the future in near-by counties in the States of Utah, Wyoming, Ne-

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[1] The predacious ladybird *Hippodamia convergens* Guér. is capable of accommodating itself to practically all climes and countries, with the exception of areas where the temperature is so high or so low that few forms of plant and insect life are able to survive.

[2] It occurs, though not as a pest, in certain other regions remote from the region specified, e. g., in Kansas and Arkansas.

braska, and Oklahoma, and later in southern California. There may even exist a wider distribution than is now known in Texas, since the localities inserted on the map plainly show such a possibility.

LIFE HISTORY AND HABITS.

SEASONAL HISTORY.

In the Arkansas Valley of Colorado, and in regions having a similar climate, two generations or "broods" of the bean ladybird develop annually.

The winter is passed in the adult stage, the beetles hibernating under tufts of grass, weeds, old vines, rubbish, and similar material, in or about the fields and gardens in which they developed. The overwintered beetles emerge from their hibernating quarters about the middle of June and, after a brief interval of feeding, mate and begin to deposit eggs.

The first eggs hatch in about a week and the adults of the first generation develop shortly after the middle of July. After an interval of a week or ten days eggs are deposited by the first generation of beetles and from these the first adults of the second generation develop. This occurs during the latter part of August or early September. A portion of the adults of the first generation and all those of the second generation deposit no eggs until June of the following year. The beetles go into hibernation during the last days of September and the first of October and, as previously stated, remain dormant until about the middle of June of the succeeding year.

It is somewhat remarkable that the beetles remain in hibernation during the last days of May and the first half of June when high temperatures, from 90° to 95° F., often prevail.

The egg-laying period of the overwintered beetles, which includes individuals of both the first and second generations, extends from shortly after the middle of June until about the 1st of August, although occasionally some of these beetles live and deposit eggs throughout the summer. The egg-laying period of the beetles of the first generation which deposit eggs during the first season extends from soon after the middle of July until well into September. Reproduction, then, continues from about the middle of June until the beans are destroyed by killing frosts in late September or early October. The insects usually cause a maximum amount of damage during July and August. The larvæ, especially those more than half grown, are voracious feeders and, as a rule, cause vastly more injury than do the beetles.

REPRODUCTION AND DEVELOPMENT.

The life-history studies of the bean ladybird were conducted in Colorado in an open-air insectary at Rocky Ford. The insects were confined in cloth-covered battery jars and fed on the foliage of string beans. A pair of beetles which developed in late August, 1914, mated August 29 and were isolated. These beetles commenced hibernation October 12, and on November 10 the rearing cage, containing earth and some dead bean leaves under which the beetles rested, was placed in the laboratory cellar. The cage remained in the laboratory cellar until May 20, 1915, when it was again placed in the open air. The beetles emerged from hibernation on June 15, and began feeding. The first eggs were deposited June 18, and from this stock the species was reared for two seasons (1915 and 1916) without a break. The record for 1915 is given in Table I and that for 1916 in Table II.

TABLE I.—*Generations of Epilachna corrupta in 1915.*

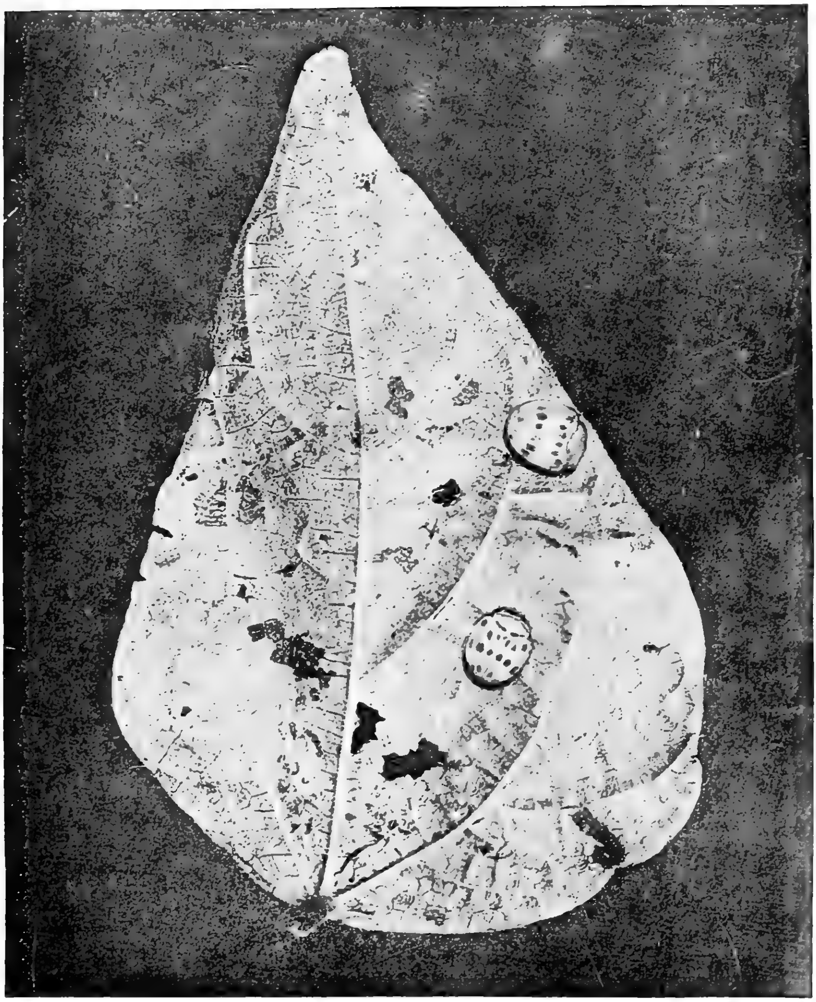
Life-history event.	First generation issued.	Second generation appeared.
Adults developed	Aug., 1914	July 19, 1915
First eggs deposited	June 18, 1915	July 30, 1915
First eggs hatched	June 25, 1915	Aug. 5, 1915
First larvæ matured	July 12, 1915	Aug. 23, 1915
First larvæ pupated	July 13, 1915	Aug. 24, 1915
First adults developed	July 19, 1915	Sept. 1, 1915
	Days.	*Days.*
Egg period	7	6
Larval period	18	19
Pupal period	6	8
Total duration	31	33

TABLE II.—*Record of the generations of Epilachna corrupta in 1916.*

Life-history event.	First generation issued.	Second generation appeared.
Adults developed	Sept. 1, 1915	July 17, 1916
First eggs deposited	June 18, 1916	July 30, 1916
First eggs hatched	June 25, 1916	Aug. 5, 1916
First larvæ matured	July 10, 1916	Aug. 21, 1916
First larvæ pupated	July 11, 1916	Aug. 23, 1916
First adults developed	July 17, 1916	Aug. 31, 1916
	Days.	*Days.*
Egg period	7	6
Larval period	16	18
Pupal period	6	8
Total duration	29	32

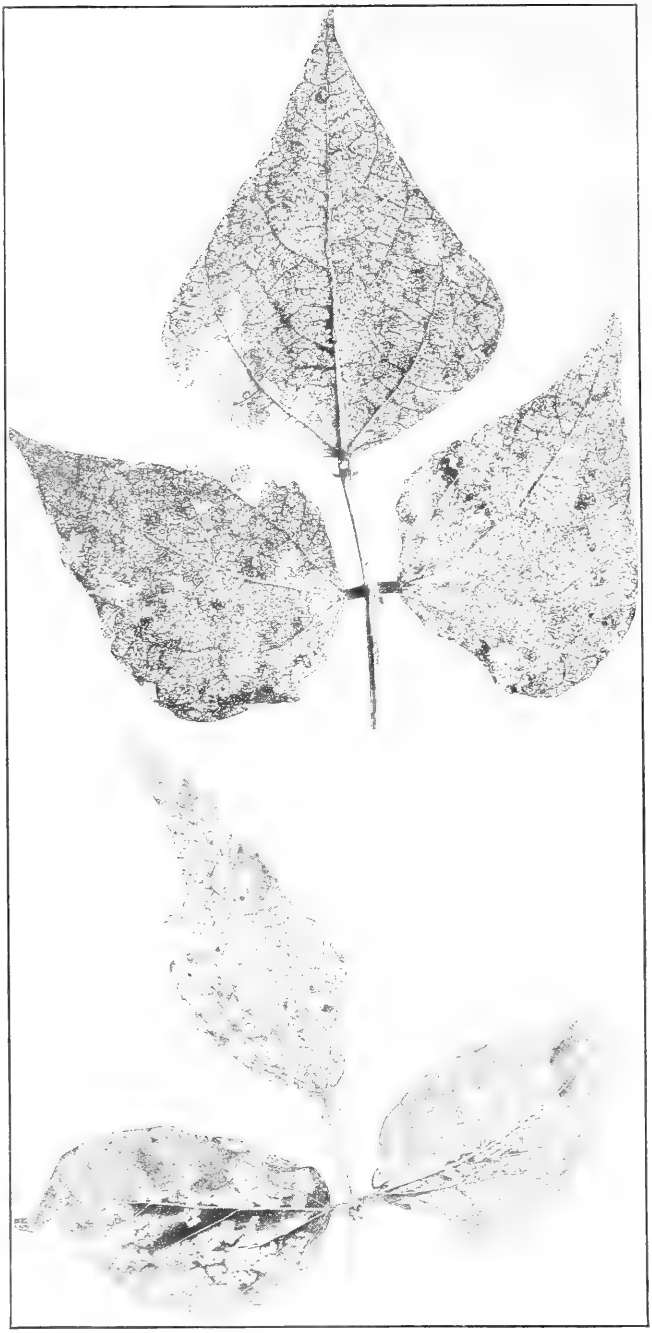
The 19 beetles which developed September 1 fed until September 23, when hibernation began. The cage was placed in the laboratory cellar November 10, 1915, and was removed to the open May 3, 1916. June 12, 16 beetles issued from hibernation, 3 having died during the winter, and began feeding. One pair mated June 13, and the record of the progeny is given in Table II.

The female died September 9. The male went into hibernation October 5, and was later destroyed. In this case the egg-laying



THE BEAN LADYBIRD.

Beetles beginning work on under surface of leaf.



THE BEAN LADYBIRD.

Bean leaves showing injury by beetle.

THE BEAN LADYBIRD.

Bean leaves skeletonized by the bean ladybird. Beetle above; pupæ in middle; larva at left near bottom. Somewhat enlarged.

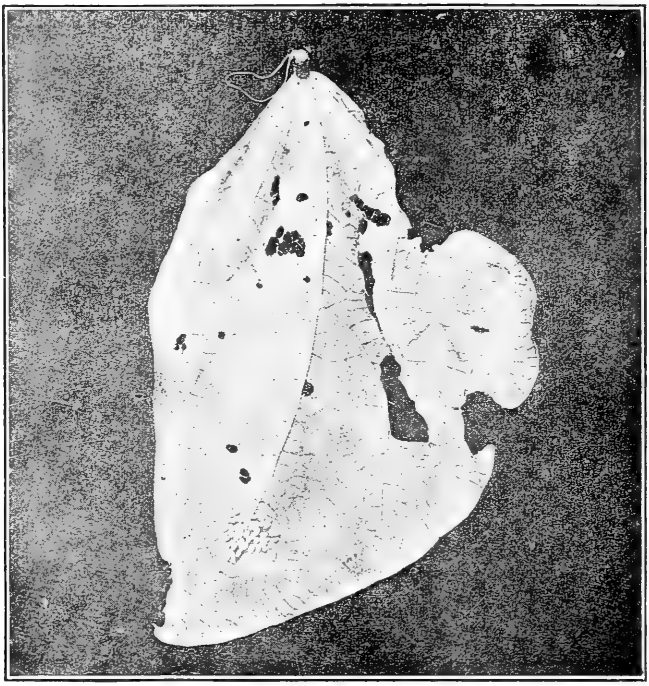


FIG. 1.—EGG MASS ON LOWER PORTION OF BEAN LEAF.

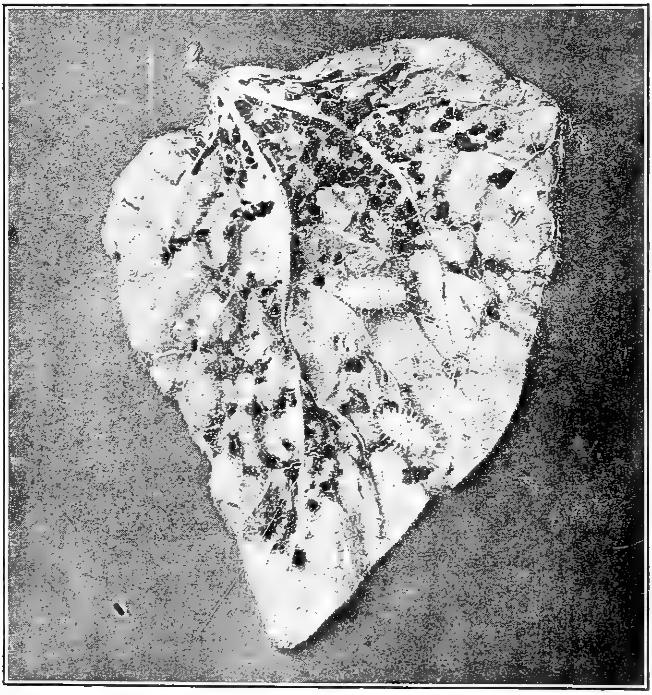
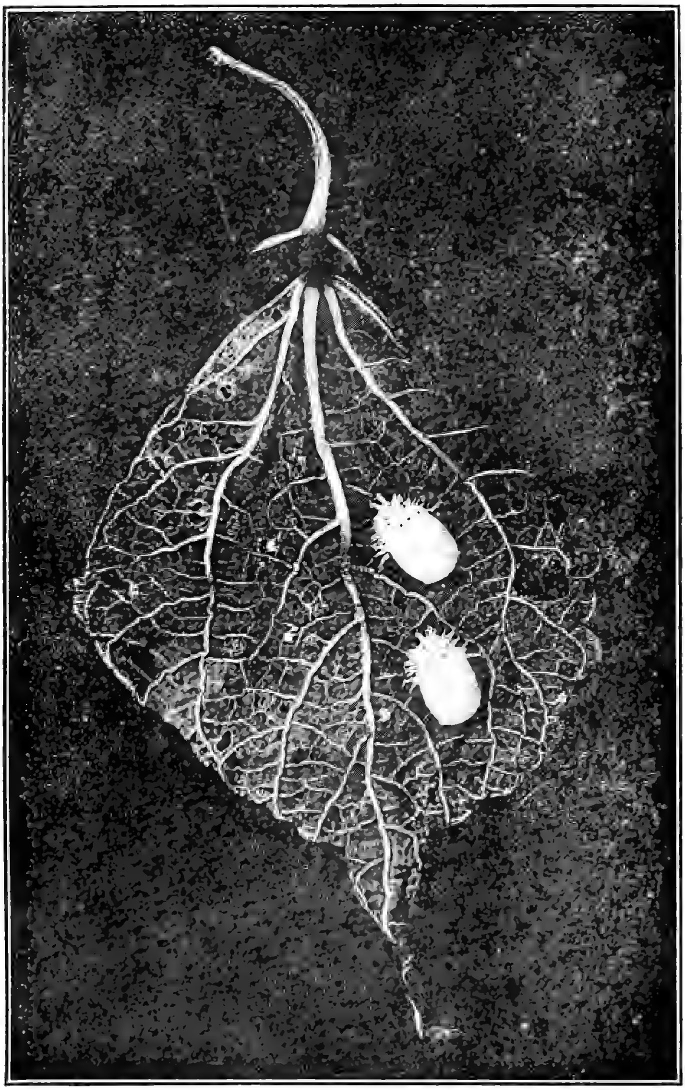


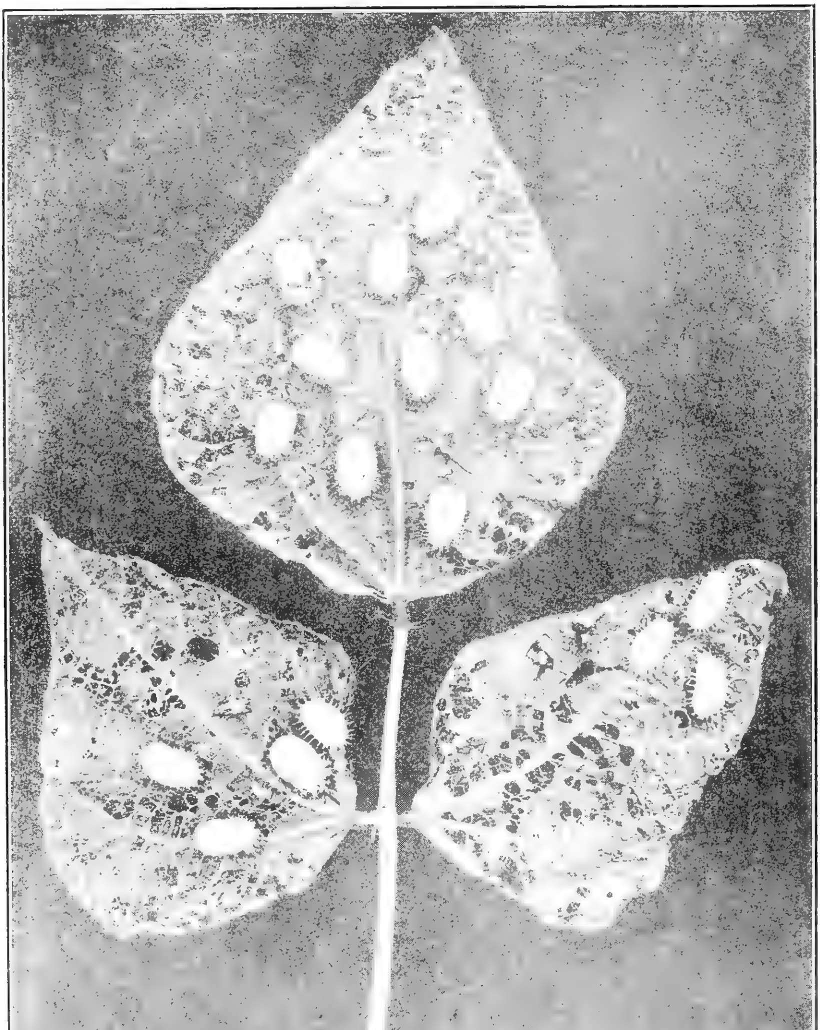
FIG. 2.—LARVÆ AT WORK ON UNDER SURFACE OF LEAF.

THE BEAN LADYBIRD.



THE BEAN LADYBIRD.

Pupæ formed on injured bean leaf.



THE BEAN LADYBIRD.

Cluster of bean leaves showing natural form of pupation on lower surface of leaf, and larva ready to transform on leaf at right.

period extended from July 25 until September 2, a total of 40 days. With other females this period covered from 35 to 70 days.

The life cycle from egg to adult and the periods of the stages by days are given in Tables III and IV respectively.

TABLE III.—*Life cycle of Epilachna corrupta.*

Event.	Date.	Event.	Date.
	1916.		1916.
Eggs deposited	Aug. 10	Larvæ molted	Aug. 30
Larvæ hatched	Aug. 18	Larvæ reached maturity	Sept. 3
Larvæ molted	Aug. 21	Larvæ pupated	Sept. 5
Larvæ molted	Aug. 25	Adults developed	Sept. 12

TABLE IV.—*Periods of stages of Epilachna corrupta.*

Instar.	Number of days.	Instar.	Number of days.
Egg period	8	Fourth larval stage period	6
First larval stage period	3	Pupal period	7
Second larval stage period	4		
Third larval stage period	5	Total	33

The beetles which developed August 31 fed, without mating or depositing eggs, until October 5, when they began hibernation. November 10, 1916, the cage was placed in the laboratory cellar and removed to the open April 17, 1917. The beetles issued from hibernation June 15, 1917, and were then killed, closing the record.

Records of egg-laying were obtained by confining single pairs of beetles, immediately after mating and before the first eggs were deposited, in small rearing jars. The beetles fed on bean leaves and the eggs were removed as deposited and counted. The number of eggs deposited by eight females of the first and second generations were: 504, 552, 616, 636, 850, 942, 1,147, and 1,516, respectively, or an average of 845 eggs to a single beetle.

A detailed record of the female of one of these pairs of beetles, which developed July 17, 1916, and mated July 22, is given in Table V.

TABLE V.—*Egg-laying record of a single female of Epilachna corrupta in 1916.*

Date.	Number of eggs deposited.	Date.	Number of eggs deposited.
1916.		1916.	
July 25	52	Aug. 15	56
July 28	50	Aug. 18	58
July 29	53	Aug. 21	55
Aug. 1	52	Aug. 23	52
Aug. 3	55	Aug. 26	52
Aug. 5	51	Aug. 28	54
Aug. 6	53	Sept. 2	51
Aug. 9	52		
Aug. 11	54	Total	850

In experiments conducted in New Mexico by Merrill (21) the period of incubation was between 4 and 9 days. The duration of the larval stage was between 15 and 21 days. The pupal period was between 3 and 5 days, and the total developmental period lasted between 22 and 28 days.

HISTORY AND LITERATURE.

The bean ladybird was described by Mulsant in 1850 (1) from Mexico as *Epilachna corrupta* and its injuries were observed in New Mexico at about the same period.

In 1883 Riley (4) published an editorial on this species with quotations from a letter from Prof. George H. Stone, which contains our first known account of the food and injurious habits of this insect. Attack by larvæ and adults was observed on leaves and pods of wax beans at Colorado Springs, Colo., August 26, 1882.

It was not until a lapse of six years that attention was called to further injury by this insect. At that time Judge J. F. Weilandy (5, 6) wrote, July 23, 1889, of injuries at Springer, N. Mex., stating that this "bean bug" committed great depredations in bean fields, often destroying them entirely. The Mexicans had found that late planting, about the middle of July, acted as a preventive of its ravages. In a letter dated July 30, in the same year, he directed attention to injury at Watrous, N. Mex., and stated that the pest had been known in that region for about 40 years. He also furnished specimens from which were recorded, editorially, the habits of two predacious ladybirds, which will be mentioned later under "Natural enemies," of feeding on the eggs of this species.

In 1892 Prof. C. P. Gillette (7) gave an account of this pest in Colorado, furnishing illustrations of the stages and manner of work.

In 1897 Rev. Henry S. Gorham (8) considered this species with the Coccinellidae of Central America, indicating the synonymy, and the distribution in Mexico, Guatemala, and Panama, with notes on variation and colored illustrations of the adult and of the larva. In this year also Mr. H. Griffin (9) reported injury at San Juan, N. Mex. Judge Weilandy furnished a list of the varieties of beans affected and reported on the effectiveness of Paris green which, although it killed the beetles, destroyed the plants as well.

In 1899 Col. Thos. L. Casey (11, p. 103) furnished a characterization of the beetle, comparing it with *E. borealis*. In 1900 Cockerell (13) stated that this species was the "bane of bean growers in New Mexico, from Chicorico Cañon * * * to the Mesilla valley." In 1902 A. N. Caudell (14) cited an instance of extreme injury to beans at Fort Collins, Colo., in 1901. The statement made by W. Knaus (15), in 1906, that this insect was damaging potato near Wootens, N. Mex., is, of course, incorrect. During 1907 Messrs.

Fall and Cockerell (16, p. 170) indicated by localities the distribution in New Mexico. In 1913 Dr. A. W. Morrill (19) published a note on the distribution of this species in Arizona. In 1915 E. O. Essig (20, p. 219) stated that this species was "said to be found in California," which is evidently incorrect as no definite locality is cited and the species is not known to breed in that State. During 1917 D. E. Merrill (21) published the first comprehensive account of this insect, with especial regard to its occurrence in New Mexico, furnishing details in regard to injuries, life economy, and distribution, and indicating methods of control. In most respects the results obtained in that State do not differ materially from those obtained in Colorado.

Popular accounts of the bean ladybird were published by Gillette (10) in 1898, Sanderson (18) in 1912, and by the writer in 1899 (12), 1907 (17, p. 109), 1917 (22, p. 28), and 1919 (23), as well as by others.

UNPUBLISHED RECORDS.

February 2, 1899, Mr. C. B. Metcalfe wrote of the bean ladybird and its injuries to the Mexican Bayo bean or frijole at San Angelo, Tom Green County, Tex. For many years prior to the date of writing growers had not succeeded in raising a crop of beans because of the ravages of this pest, which destroyed the plants by eating the leaves. Metcalfe described the larva as a humpbacked yellow insect about one-fourth inch long and of the color of sulphur, with a hairy-looking covering which changed afterward to the hard-backed grown "bug." He described the larva as destroying the green part of the leaves leaving only a thin tissue. During the same year Mr. James K. Metcalfe, Silver City, N. Mex., wrote that this species was quite injurious to beans in his vicinity, and furnished specimens in different stages. At this time, September 14, larvæ were quite scarce, most of those sent having transformed to pupæ.

August 8, 1904, Oscar Liffreing, Bernardo, N. Mex., sent specimens, mostly pupæ and newly developed beetles, with the report that they were devouring all of the early beans in that region. August 26 of the same year specimens were received from Mr. Liffreing, with report of injury to beans. July 26, 1905, Mrs. V. A. Armstrong reported injury to beans at Fort Collins, Colo., furnishing specimens of larvæ, and leaves and pods showing injury.

September 6, 1908, F. H. Headley reported injury at Fort Collins, stating that this insect was doing a great amount of damage to the bean crop in that section. July 15, 1909, B. F. Morris, Santa Cruz, N. Mex., wrote as follows: "I am sending some chinch bugs, the insect which is working destruction to the bean crop here, and is now depositing its eggs." During 1909 M. C. Stevenson, Espanola,

N. Mex., reported injury, July 24, to beans, furnishing samples of adults. August 11, M. A. Bishop reported injury at Tularosa, N. Mex. He wrote that for two years previously a small yellow bug covered with hairs had been eating the leaves of beans leaving nothing but a bare skeleton. Complaint was also made by Mrs. Katherine Courtney of injury to lima beans at Littleton, Colo.

May 28, 1910, Elias Clark, Alcalde, N. Mex., stated that this insect was very destructive to beans in that vicinity. January 11, 1909, John Block, Santa Cruz, N. Mex., described the larvæ, adults, and the work of this species on beans, requesting a remedy. July 6, 1915, Mrs. Ethel Mercer wrote from Denver, Colo., of little yellow larvæ which literally devoured the bean crop. They began on the leaves, and after these were gone they attacked the pods, as many as 15 being noted on a pod. Before the beans began to bloom the same insect ate the leaves "full of holes."

August 28, 1912, this species, according to Dr. A. W. Morrill, did considerable damage to beans at Prescott, Ariz. At that time it was abundant mostly in the pupal and adult forms. Between July and August of the following year, 1913, much damage was noted to pole beans at Cottonwood, Ariz. The insects practically ruined an entire field of about one-half acre. At that time full-grown larvæ and pupæ and a few egg batches and young larvæ were found. The hibernating adults had disappeared, only newly emerged, pale yellow adults being in evidence.

October 13, 1916, W. E. Marble wrote in regard to the growing of Mexican beans in the Arroyo Animas Valley of New Mexico, stating that the crop was greatly damaged by the larvæ of this ladybird which he described as of about the size of a navy bean, yellow in color, eating the leaves, and leaving only a network. This, he wrote, stops the growth of the plants and ultimately kills them. October 16, A. Warner, Sandy, Ariz., sent specimens, stating that the insect destroyed a crop in about 14 days, and that Paris green was ineffective.

Complaints were made during the year 1917 of injury at Wheatridge, Brewster, Colorado Springs, Rocky Ford, Pueblo, Denver, and Boulder, Colo.; Santa Fe and East Las Vegas, N. Mex.; Flagstaff, Ariz.; and Alpine, Tex. The last report was from T. F. Blaine, dated October 31, and was accompanied by specimens. D. E. Merrill also wrote of this species October 5, 1917, and of its occurrence in the vicinity of El Paso, Fabens, and Clint, in the El Paso Valley of Texas.

F. M. Wadley, scientific assistant, stated June 21, 1918, that the bean ladybird occurred at Wichita, Kans., but was more abundant in the western part of the State. August 6, Thomas H. Hudson complained of injury by this species to beans at Colorado Springs, Colo.

During January, 1919, A. E. Mallory, scientific assistant, wrote in regard to the occurrence of this species at Greeley, Colo., that he had observed the beetles feeding on the underside of the leaves of the mammoth soy bean (*Soja hispida*) in that vicinity. The previous December he found the beetles hibernating under a pile of bean vines. Until the receipt of this last record the species was believed to feed exclusively on table beans.

February 11, 1919, W. A. Williams, Venus, N. Mex., reported injuries by this species to pinto beans in that vicinity. Failure to obtain rain was ascribed as one of the causes of injury. Mr. Williams stated that "on beans these little 'bugs' eat the leaves full of holes and damage the crop considerably." During January and February a number of other complaints were made of injury by this species in New Mexico and Colorado. Other complaints of injury, unaccompanied by specimens, and requests for information in regard to methods of control have been received from other sources, notably Parsons, Kans., Jemez Springs and Nogal, N. Mex., Griffith, Colo., and Kirkland, Ariz.

April 3, 1919, the State entomologist, Dr. C. P. Gillette, collaborator, wrote in regard to the occurrence of this species in Colorado as follows:

> We have records of this species from the points which you mention and others near them, and also from Nucla, in the Paradox Valley, Montrose County; from Cortez, in Montezuma County; and from near Greeley, in Weld County. It seems likely that the infestations in the southwestern part of the State are from New Mexico. It has seemed very strange to me that this beetle keeps so close to the foothills, never going out far upon the plains, except down the Arkansas Valley. The beetle was abundant here when I first arrived at Fort Collins, 28 years ago, and it apparently has never occurred as far east as Greeley, about 24 miles from the foothills. I have found it to be a species about equally abundant every year, although there is some fluctuation in numbers. It was very bad last year in the northern section, from Pueblo to Fort Collins, along the eastern foothills, and extended a few miles into the plains.

Writing on this species September 2, 1919, Mr. Fabian Garcia, horticulturist, New Mexico Agricultural Experiment Station, State College, N. Mex., stated that this insect is a serious pest in New Mexico, particularly in the older bean-growing sections, and that it causes the bean growers there a lot of trouble and expense. He expressed the opinion that the losses could be materially reduced by properly spraying.

NATURAL CONTROL.

EFFECT OF CLIMATIC CONDITIONS.

Cold weather appears to be the most important natural check to the development of the bean ladybird in Colorado. This insect is a southern species which apparently has not become fully adapted to northern climates. This is not a theory but is based on facts. It is indicated by the fact that many eggs, larvæ, and pupæ occur so late in the fall that they are killed by freezing. Many larvæ starve because the foliage of the bean plants on which they had been feeding was destroyed by early fall frosts. It is also not uncommon to find many dead adults in their hibernating quarters where they had been killed by winter temperatures.

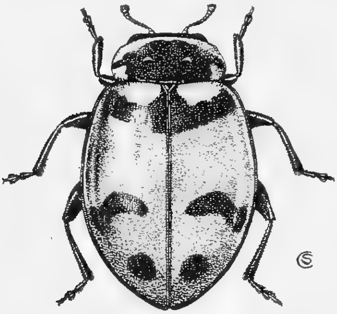


FIG. 3.—The five-spotted ladybird (*Hippodamia 5-signata*), an enemy of the bean ladybird. Enlarged.

NATURAL ENEMIES.

The insect enemies of the bean ladybird are, as far as has been learned, not particularly effective in holding it in abeyance. The beetles are well protected by their firm elytra or wing covers and by a repellent yellow liquid which oozes from their knee joints in small drops when the insects are disturbed. This liquid possesses a disagreeable odor and doubtless a similar flavor, which, it is believed, may protect the beetles from the attacks of natural enemies.

June 27, 1916, two overwintered female beetles were collected at Rocky Ford, Colo., each with the egg of a tachinid fly attached to one of its elytra. One of these beetles died September 4, and the other September 9. Fertile eggs were deposited at frequent intervals from June 29 until September 5, and no parasites developed. This is the only evidence noted of insect parasites.

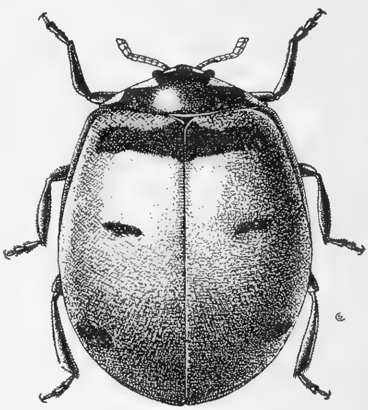


FIG. 4.—Transverse-spotted ladybird (*Coccinella transversoguttata*): Adult beetle. Much enlarged.

Morrill has reported an undetermined ant observed eating the eggs on one occasion.

The adults of three species of predacious ladybirds are known to be natural enemies of this insect. They are: The convergent ladybird (*Hippodamia convergens* De G.); the five-spotted ladybird (*Hippodamia 5-signata* Kby., fig. 3), and the transverse-spotted ladybird (*Coccinella transversoguttata* Fab., fig. 4).

These have been reported as destroying the eggs of the bean ladybird, and next to cold are the most effective known factors in its natural control in Colorado and neighboring States.

The first species occurs in abundance throughout the country and is our most useful ladybird, having been transported from one part of the country to another and to foreign countries. The other two are commonly found in the region inhabited by the bean ladybird, but more especially in the middle Northwest. Both species, however, extend their range to Washington and Oregon.

The larvæ are apparently well protected from insect enemies by the branched spines with which the body is armed. In one case, however, the larva of a lacewing fly (*Chrysopa* sp.) was observed sucking the juices from a partially grown Epilachna larva.

No insect enemies of the pupa and no fungous or other disease have been observed to affect the living insect in any stage.

PREVENTIVE MEASURES.

HAND PICKING AND BRUSHING.

The bean ladybird is difficult to control. In small gardens hand-picking the eggs, larvæ, and adults has given satisfactory results. The greatest measure of success has come from gathering and destroying the overwintered beetles soon after their emergence from hibernation and before they have had an opportunity to deposit eggs. The beetles, being sluggish like the Colorado potato beetle, are readily hand picked.

Another method which has afforded some degree of success consists in brushing the larvæ from the foliage to the earth between the rows. This can be accomplished by striking the plants with the bare hand, with a bunch of weeds, or with a paddle fashioned for the purpose from a shingle. If the brushing is done during dry hot weather very few, if any, of the larvæ are able to return to the plants.

CLEAN CULTURAL METHODS.

With the knowledge that the adults of the bean ladybird pass the winter under old vines, tufts of grass, weeds, and other useless material, the numbers of beetles may be materially reduced by burning in late fall or early spring all rubbish of this nature along ditches and fence corners and in similar locations. Everything possible should be done to destroy these winter quarters, as their destruction will afford a considerable measure of protection from injury, if done by a community year after year.

EARLY AND LATE PLANTING.

Proper attention to the time of planting will prevent considerable injury by this as well as many other species of insect pests.

By planting earlier than usual this can be accomplished, as well as by planting considerably later, or as late as a crop can be assured. Since the overwintered beetles do not begin to feed until very late, planting early will accomplish much, enabling the plants to make such good growth that insect damage coming late may be immaterial.

Late planting should be so timed that the plants will come up after the overwintered beetles have about ceased feeding and, at the same time, early enough to secure a good crop before frost time. No definite time can be assigned for early or late planting for the entire range of this species; it is a matter for the growers themselves to determine. Community work should accomplish much along this line, in determining both the times for planting and the effect of this method.

It has been suggested that early planting be practiced in a community for a series of years and then late planting for a year or two succeeding this.

Whatever can be done toward lessening the number of insects in a community during a given year will have a correspondingly greater effect for the coming season.

DIRECT MEASURES OF CONTROL.

EXPERIMENTS WITH INSECTICIDES.

Numerous spraying experiments were made with arsenate of lead, Paris green, arsenite of zinc, and nicotine sulphate. The experiments were conducted on moderately infested plots of string beans. The spray was applied to both the upper and lower surfaces of the leaves with a portable compressed-air sprayer, fitted with an extension rod, elbow, and disk-type nozzle having a fine aperture.

ARSENATE OF LEAD.

Arsenate of lead was applied at the rate of 1½, 2, 2½, and 3 pounds in powdered form in 50 gallons of water. The spray adhered well and evenly to the foliage, but the effect was very uncertain on the bean foliage as was also the killing effect on the insects. The injury from burning varied greatly with the age and tenderness of the plants, the older, tougher foliage usually escaping appreciable injury, while on the younger, more tender plants the burning effect was serious, especially where the stronger doses were applied.

In summing up the experiments in spraying with powdered arsenate of lead the results were so uncertain that one is hardly justified in recommending this insecticide as a reliable agent for controlling the bean ladybird on string beans.

One experiment was made with arsenate of lead paste at the rate of 6 pounds to 50 gallons of water. This burned the beans so badly that they were almost completely destroyed. Most of the larvæ were killed, but the majority of the beetles escaped injury. This test indicates that paste arsenate of lead is even more injurious to bean foliage than the powdered form, and that the killing effect on the adults of the bean ladybird is equally uncertain.[1]

In experiments conducted by Merrill (21) in New Mexico powdered arsenate of lead was used at the rate of 2 and 2½ pounds to 50 gallons of water without damage to the plants. Most of the beetles

[1] The tests herein mentioned were conducted with standard or acid lead arsenate. Neutral (diplumbic or triplumbic) lead arsenate, in experiments at Washington, D. C., applied at standard dosage, caused no injury to bean foliage.

left these plants at once. Larvæ hatching from eggs deposited before the application of the poison were also killed where they fed on sprayed leaves. The older larvæ, however, appeared to die of starvation rather than from eating the poisoned foliage.[1]

ARSENITE OF ZINC.

Experiments were made with powdered arsenite of zinc at the rate of 1 pound to 20, 30, 40, and 60 gallons of water, respectively. The burning effect on the foliage was in all cases less than where arsenate of lead or Paris green was applied, and usually a larger proportion of the insects was killed. The burning was most apparent about the margins of the holes made in the leaves by the insects in feeding. Many larvæ died after eating the poisoned foliage, but, as with the other arsenicals, the effect on the beetles was uncertain. All factors considered, the most promising results were obtained with zinc arsenite at a strength of 1 to 40. This caused comparatively slight burning and killed an appreciable number of the insects. It should not be overlooked, however, that the killing of the beetles is uncertain and that the burning effect on the plants will vary greatly with their age and tenderness. It is probable that Mexican beans, with relatively tougher foliage, would show less injury from burning than the more tender-leaved string beans treated in these experiments. Zinc arsenite in experiments conducted in New Mexico by Merrill at the rate of 2 pounds to 50 gallons of water produced practically the same results as powdered lead arsenate.

PARIS GREEN.

Experiments were made with Paris green at the rate of 1 pound to 60 and to 80 gallons of water. As a result of these tests the beans were destroyed by burning due to the presence of free arsenic. Most of the larvæ were killed, but many of the beetles escaped. In the face of these results, Paris green at these strengths can not be recommended as a means of controlling the bean ladybird. Everyone who has tried Paris green has experienced the same failure. Sodium arsenite is at least equally dangerous.

SUMMARY OF SPRAYING EXPERIMENTS.

The experience of entomologists in spraying with arsenicals in Colorado and New Mexico tends to show that arsenate of lead acts largely as a repellent rather than as an insecticide, which is true also of its effectiveness in the case of such other pests as the striped cucumber beetle.

Bordeaux mixture, which has come to be considered a standard repellent against flea-beetles, should be tested against the bean ladybird in the future.

[1] Powdered lead arsenate at the rate of 5 pounds to 50 gallons of water was no more effective but did no damage to the plants in experiments made. It should not be used at this strength.

Additional experiments are necessary with arsenate of lead and arsenite of lime, alone and in combination with Bordeaux mixture.

NICOTINE SULPHATE INEFFECTIVE.

In another series of experiments larvæ about one-fourth grown were sprayed with nicotine sulphate at the rate of 1 ounce to 2, 4, and 6 gallons of water, respectively. The larvæ apparently were protected by their spines and the applications were in all cases absolutely ineffective. The only noticeable effect was that the larvæ appeared somewhat stupefied for a brief interval.

COOPERATION.

In the control of this pest, as with so many others which are difficult to destroy, combined effort on the part of the bean growers of the community is essential to success. Whatever can be done in cooperation to lessen the numbers of this insect in one season is felt the next season and if it were rigidly continued would mean the eventual saving of the crop.

SUMMARY OF CONTROL MEASURES.

In the light of our present knowledge the best methods of controlling the bean ladybird may be summarized as follows:

(1) For small gardens and similar areas hand pick the overwintered beetles as soon as possible after they emerge from hibernation.

(2) Brush the larvæ, or young, from the plants during hot, dry weather.

(3) Spray with arsenite of zinc, at the rate of 1 pound to 40 or $1\frac{1}{2}$ pounds to 50 gallons of water, or with arsenate of lead 1 or 2 pounds (powder) to 50 gallons of water.

(4) Clean up the fields by removing dead grasses, weeds, and other possible hibernating quarters during the fall or winter months, and destroy them by burning, or by simply burning over the fields when this practice can be safely followed.

(5) Early and late planting should be practiced. No specific time can be indicated for this that would apply to the entire region which the insect inhabits, and it is more satisfactory for the growers to work out this problem for themselves.

(6) In the case of large areas of beans, close inspection is strongly recommended. Infestation usually begins in small, localized areas, and if these infested spots are located and prompt measures, as indicated in the preceding paragraphs, are taken to destroy the insects a general infestation can be prevented.

GENERAL SUMMARY.

The bean ladybird is a serious pest on beans of all kinds, including the soy bean, in Colorado, New Mexico, Arizona, and western Texas. It frequently destroys entire crops and the conservative estimate of the annual losses incurred is placed at 10 per cent of the crop. This insect feeds normally on the leaves, and attacks also the young pods and occasionally eats into the blossoms. The beetles feed chiefly on the upper surface, cutting irregular holes in and through the leaves, while the larvæ feed on the lower surface and skeletonize the leaves, seldom cutting through them.

The adult is a robust beetle, about one-fourth inch in length, of oval outline, pale brown, with each wing-cover marked with eight small black spots. The larva is light yellow and armed with branched spines.

The yellow eggs are deposited from about the middle of June until August on the lower surface of the leaves, in clusters of 40 or more, and sometimes to the number of 1,500 by a single female. The larvæ feed at first in colonies, but with larger growth scatter and become more or less solitary. The life cycle may be passed in summer in from 22 to 30 days; the eggs hatch in from 4 to 9 days; the larval period is between 15 and 21 days; and the pupal period varies from 3 to 6 days. In colder weather, however, these periods are longer. Two generations or "broods" are produced annually.

Fig. 5.—Traction sprayer with nozzle arrangement for side spraying, of type useful for spraying beans for the bean ladybird.

Cold weather in late autumn has the effect of destroying the insects, and their eggs are also destroyed by three species of predacious ladybirds.

In the control of the bean ladybird preventive measures are the most efficient, consisting of hand picking and brushing from the plants, clean culture, and early and late planting. Arsenicals possess some killing properties, but in the main act as repellents. Spraying with arsenate of lead, 1 or 2 pounds (powder), and with arsenite of zinc, 1 to $1\frac{1}{2}$ pounds (dry), to 50 gallons of water, are the most promising. Bordeaux mixture, 4–4–50 formula, should be used alone and in combination with these arsenicals. Additional tests must be made with these substances to ascertain the most effective and economical combination that may be applied to the bean plants without scorching or burning the leaves.

For the treatment of large areas infested by the bean ladybird, a traction sprayer with nozzles arranged for side spraying of the type shown in figure 5 is useful. Owing to the danger of scorching bean foliage, it is desirable that an up-to-date sprayer should always be used.

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THE BEAN LADYBIRD IN COLORADO IN 1919.

By A. E. Mallory, *Scientific Assistant.*

LIFE-HISTORY RECORDS.

Hibernating adults of the bean ladybird which had passed the winter successfully began to appear in Colorado in 1919 about the middle of June, the first individuals having been found June 16 feeding on beans. A week to 10 days later they began to deposit eggs on the underside of the leaves in clusters of about 40 or more. About 2 weeks later, July 9 and 10, the eggs hatched, and the tiny yellow larvæ commenced to feed in a colony near the egg cluster. As they grew older they became separated and did not necessarily confine their feeding to the underside of the leaf. As the season advanced, they fed on every part of the plant, blossoms and pods included. The larvæ were present in all stages from the first appearance until at least September 10. On July 22, which was 10 or 12 days after the eggs had hatched, pupæ were found. During the early part of the season, when foliage is plentiful, pupation takes place on the underside of the leaf. In case the foliage has been extensively destroyed pupation may take place on either side of the leaf or on both sides, 25 to 30 pupæ on a single leaf being not uncommon. As many as 100 on a single leaf were reported in a case where infestation was heavy. This congregating at the time of pupation seems to be characteristic of the species. Pupæ were observed on other plants near beans when the foliage of the beans was almost destroyed.

On July 28 adults of the first brood were observed, and by July 30 they were numerous, gradually increasing in number until about September 1 when they seemed to reach their maximum numbers. The first-brood adults are much lighter in color than the hibernating individuals, being a bright yellow at the time of emergence. They gradually become darker, and at hibernating time some are dark reddish brown, almost if not entirely as dark as the hibernating individuals. Eggs deposited by this new brood were observed August 28 and September 2. It is possible that eggs were deposited by this brood earlier than these dates.

There is no definite place in the life history of this species to separate the different broods. Apparently there are two broods or at least a partial small second brood for this locality. The fact that larvæ were observed in all stages of development during the entire season would suggest two broods. Further, the fact that first-brood adults began issuing rather late, and that so few egg clusters were found in late August and September, would suggest only a partial second brood.

SUMMARY FOR 1919.

Hibernating adults appeared	June 16.
Beetles present in large numbers by	June 25.
Beetles began depositing eggs	June 25.
Eggs began hatching	July 10.
Larvæ began to transform to pupæ	July 22.
Adults of first generation issued	July 28.
Egg clusters, second brood, found	August 28. September 2.
Maximum numbers first-brood adults observed	September 1.
Adults began to become sluggish	September 10.
Maximum damage accomplished	August 1 to September 1.

Second-brood eggs were probably deposited, but not observed, before August 28.

INJURY.

The bean ladybird so far as observed confines its feeding to beans, and when taken on other plants is never found feeding. The variety of beans seems to make no particular difference as to susceptibility to attack. The adults do not attack the very young plants to any considerable extent. This fact is probably due to the small number of hibernating individuals. Furthermore, the overwintering adults do not concentrate their attack, but move from plant to plant. Thus the damage is less noticeable. Although the adults usually eat entirely through the leaf, they often merely scrape the surface, leaving a network of veins plainly visible. Later in the season as the foliage begins to die they attack the pods, sometimes completely riddling them, but usually eating out small spherical holes here and there along the pod. In the case of canning beans this injury may cause considerable loss, while on seed beans it is not so serious.

The percentage of injury by a number of adults is small as compared to that caused by an equal number of larvæ. The larvæ begin their attack on the leaves, invaribly feeding at first on the underside. Instead of eating through they scrape the surface, leaving the skeleton of the leaf in plain view, although with continued feeding in a limited space they may riddle the foliage.

Maximum damage occurred in this locality during the month of August. This is the period when the new adults are feeding along with the larvæ, and the two broods of larvæ overlap. Damage was generally worst near fences, along ditch banks, and on beans receiving an extra amount of water by accident or seepage.

There is a large area in northeastern Colorado devoted to farming and stock raising. This area is known as the Greeley District. Beans of all varieties are grown quite extensively. Several thousand acres are planted to beans every year. A conservative estimate of the damage done to the whole bean crop in that district during the season of 1919 by the bean ladybird is about 5 per cent. This estimate at first may seem rather small, but the majority of fields were infested lightly or not at all. In the second place a few fields were more heavily infested than the adjacent or neighboring fields. In those fields coming under our observation the damage by *Epilachna corrupta* varied from an estimated 25 per cent to 65 per cent. One field in particular, of about 15 acres, was damaged at least 65 per cent if not 75 or 80 per cent. No remedial measures were applied in this case.

CONTROL.

In some of the small truck patches the attack of the bean ladybird was controlled by hand picking. In view of the distribution of the damage, as stated, clean farming or destruction of winter quarters is suggested as an important measure of control.

As to remedial measures, all possibilities were not worked out. On July 10 when the first larvæ were observed, the following sprays were tested on large plots in a 9-acre field. Right-angle mist-producing nozzles were used. Approximately 80 per cent of the leaves were covered on one side or the other, the remainder varying from a small amount to none at all. The foliage was heavy.

Experiment No. 1.—Lead arsenate, powder, was used at the rate of 2 pounds to 50 gallons of water, with 2 pounds of hydrated lime added. Very little if any damage was noted from the spray. A few dead larvæ were found.

Experiment No. 2.—Lead arsenate, paste, was used at the rate of $2\frac{1}{2}$ pounds to 50 gallons of water. No damage to the plants was noted.

Experiment No. 3.—Zinc arsenite, paste, was applied at the rate of 2 pounds to 50 gallons of water. This strength caused no damage to the plants.

Experiment No. 4.—Bordeaux mixture, alone, formula 3–6–50, was applied to a plot. No damage was done to the plants. This application seemed to be as effective as any of the foregoing during the earlier part of the season, but this plot showed a greater maximum damage after August 1 than did any of the others. The remainder of the field and a second field of 21 acres were sprayed with the same material and formula as number 1, viz, 2 pounds of lead arsenate, 2 pounds of hydrated lime, and 50 gallons of water.

Observations following these applications revealed a few dead larvæ. To locate dead larvæ was a difficult matter. Our opinion is that many were killed at the first feeding. If not killed then or very soon after, they fed to maturity. Up to August 1 all remedies tried seemed to be equally effective, the amount of damage to the plant being about the same for each plot. Undoubtedly these insecticides held the beetles and larvæ in check. The 9-acre field had an unusually large number of hibernating beetles. After August 1 the damage seemed to increase quite rapidly, and was worse on the Bordeaux plot than on any of the others. A small unsprayed plot was entirely destroyed, most of the injury here being done before August 1.

A second spraying two weeks later, about July 25, might have almost if not entirely controlled the attack.

In A. B. Owen's field of 9 acres, where spraying experiments were conducted July 10 and 11, the estimated damage was 12.5 per cent. It is believed that approximately 65 per cent of the larvæ hatching before July 25 must have been killed by the lead arsenate or zinc arsenite. The number of adult beetles found in this field in early July undoubtedly was large enough to have damaged the crop to the same extent as in the special field mentioned above. This experiment, while not of the type anticipated, demonstrates that the attack of this species can be controlled by the use of either lead arsenate or zinc arsenite.

A second spraying between July 25 and August 1 is recommended as very promising in controlling the insect, since it is at about this time that the second brood begins to appear. The two broods overlap, and the damage they do begins to increase very rapidly from this time on.

The combination spray consisting of Bordeaux mixture and an arsenical is also a promising experiment. Undoubtedly the Bordeaux mixture, in case it proves a repellent against this insect, will serve as an important fungicide. It will add very little to the expense of spraying, and will possibly increase the yield several bushels per acre by controlling minor fungous diseases.

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BULLETIN No. 844

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

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SWEET-CLOVER SEED.

Part I.—Pollination Studies of Seed Production.

Part II.—Structure and Chemical Nature of the Seed Coat and Its Relation to Impermeable Seeds of Sweet Clover.

By H. S. Coe, *formerly Assistant Agronomist, Office of Forage-Crop Investigations*, and J. N. Martin, *Professor of Morphology and Cytology, Iowa State College.*

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Part I.—POLLINATION STUDIES OF SEED PRODUCTION.

UNSATISFACTORY YIELDS OF SWEET-CLOVER SEED.

In some sections of the country much trouble has been experienced for a few years past in obtaining satisfactory yields of sweet-clover seed. This difficulty has been due for the most part to the following causes: (1) To cutting the plants at an improper stage of development, (2) to the use of machinery not adapted to the handling of the crop, (3) to the shedding of immature pods, and (4) possibly to the lack of pollination. As the first two have been overcome, mainly because of a better understanding of the requirements for handling this crop, the subject matter of this bulletin is concerned primarily with the factors which produce the third and fourth causes.

Where the production of seed was disappointing although the plants produced an abundance of flowers, it has been observed that many apparently were not fertilized, or if fertilized the pods aborted. In order to obtain data in regard to the causes of the failure of sweet clover to produce a normal seed yield, a study was made of the insects which were most active in pollinating the flowers, the source of the pollen necessary to effect fertilization, and the conditions under which the flowers must be pollinated in order to become fertilized. The relation of environmental conditions to the shedding of immature pods was also investigated. In order to overcome local environmental factors as much as possible, the experiments were conducted on the Government Experiment Farm at Arlington, Va., and in cooperation with the botanical department of the Iowa State College at Ames, Iowa.

PREVIOUS INVESTIGATIONS OF THE POLLINATION OF SWEET CLOVER.

Since Darwin (4, p. 360)[1] published the statement that a plant of *Melilotus officinalis* protected from insect visitation produced but a very few seeds, while an unprotected plant produced many, other scientists have investigated this subject. Knuth (19, v. 1, p. 37), in giving a list of the best known cases of self-sterility in plants, mentions *Melilotus officinalis*. The same author (19, v. 2, p. 282) states that since the stigma projects beyond the anthers, automatic self-pollination is difficult, and for the same reasons Müller (29, p. 180) believes that self-fertilization is not apt to occur.

In 1901 Kirchner (18, p. 7) covered a number of *Melilotus alba* racemes with nets. On one of the plants 12 protected racemes produced 187 seeds and on another plant only one seed was obtained from 10 covered racemes. This experiment was duplicated in 1904, with the result that 40 netted racemes produced an average of 38 seeds each. Kirchner concluded from this experiment that spontaneous self-pollination occurs regularly even though the stigma projects above the anthers. He (18, p. 8) also performed an experiment with *Melilotus officinalis* in 1901. At this time 16 isolated racemes produced a total of 11 seeds. This experiment was repeated in 1904, with the result that 16 protected racemes produced an average of 14 seeds each. As the racemes on one of the plants that was protected

[1] The serial numbers in parentheses refer to "Literature cited," pages 36-38.

in 1904 died, Kirchner concluded that the flowers of *M. officinalis* were especially sensitive to inclosure in nets and that the failures to obtain more than a very few seeds on protected racemes in Darwin's experiment and in his first experiment were due to this cause.

According to Kerner (17, v. 2, p. 399) the peas and lentils (Pisum and Ervum) and the different species of horned clover and stone clover (Lotus and Melilotus) as well as the numerous species of the genus Trifolium and also many others produce seeds when insects are excluded from the plants, and only isolated species of these genera gave poor yields without insect visitation.

OUTLINE OF POLLINATING EXPERIMENTS.

The yield of sweet-clover seed varies greatly from year to year in many parts of the United States. It has been assumed that this variation was due to climatic conditions, as excellent seed crops were seldom harvested in seasons of excessive rainfall or of prolonged drought just preceding or during the flowering period. The lack of a sufficient number of suitable pollinating insects also was thought to be an important factor in reducing seed production. This was especially true where the acreage of sweet clover was large and where few, if any, honeybees were kept.

In order to obtain data upon the factors influencing the yield of seed, a series of experiments was outlined to determine (1) whether the flowers are able to set seed without the assistance of outside agencies, (2) whether cross-pollination is necessary, (3) the different kinds of insects which are active agents in pollinating sweet clover, and (4) whether a relation exists between the quantity of moisture in the soil and the production of seed.

The racemes containing the flowers which were to be pollinated by hand were covered with tarlatan before any of the flowers opened and were kept covered except while being pollinated until the seeds were nearly mature. This cloth has about twice as many meshes to the linear inch as ordinary mosquito netting and served to exclude all insects that are able to pollinate the flowers. When entire plants were to be protected from all outside agencies, cages covered with cheesecloth, glass frames, or wire netting were used.

A preliminary study of the pollination of *Melilotus alba* and *M. officinalis* showed that both were visited by the same kinds of insects and that both required the same methods of pollination in order to set seed. On this account *M. alba* was used in most of the experiments reported in this bulletin. Where *M. officinalis* was employed it is so stated.

STRUCTURE OF THE FLOWERS OF MELILOTUS ALBA.

The racemes of *Melilotus alba* contain from 10 to 120 flowers with an average of approximately 50 per raceme for all of the racemes of a plant growing under cultivation in a field containing a good stand.

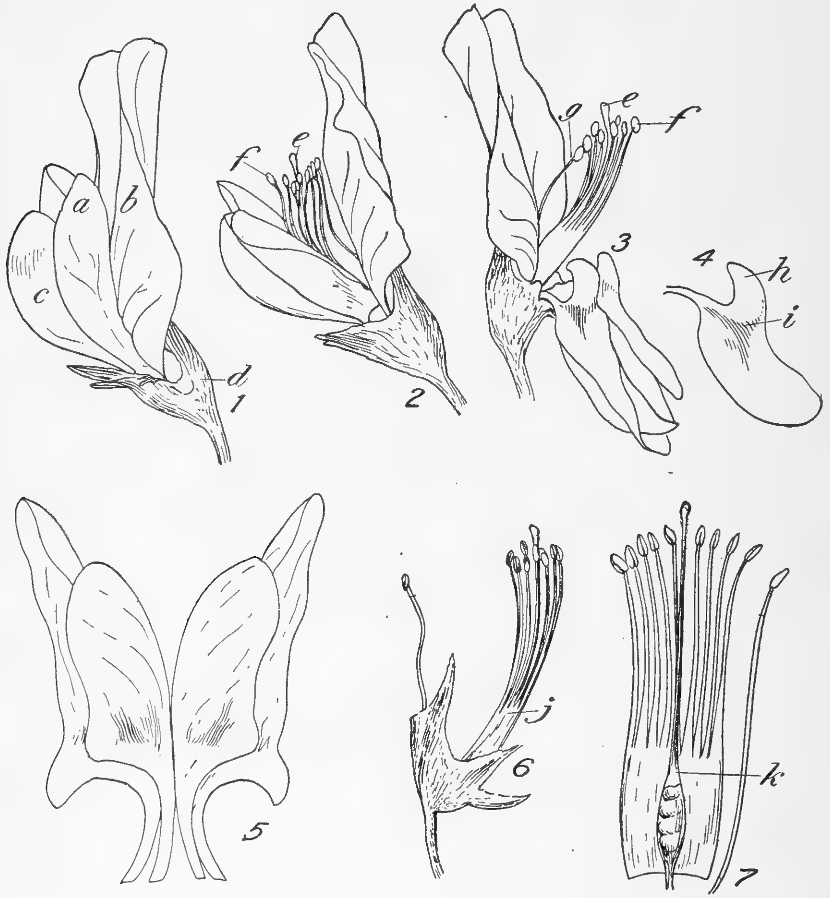


FIG. 1.—Different parts of the flower of *Melilotus alba:* 1, Side view of the flower; 2, side view of the flower with the carina and alæ slightly depressed; 3, side view of the flower, showing the carina and alæ depressed sufficiently to expose the staminal tube and the tenth free stamen; 4, ala; 5, alæ and carina spread apart to show their relative position and shape; 6, flower after the petals have been removed, showing in detail the calyx and staminal tube; 7, the staminal tube split open to show the relative size and position of the pistil. *a*, Alæ; *b*, vexillum; *c*, carina; *d*, calyx; *e*, stigma; *b*, anthers; *g*, tenth free stamen; *h*, digitate process of the superior basal angle of an ala; *i*, depressions in the ala; *j*, staminal tube; *k*, pistil.

The flower consists of a green, smooth, or slightly pubescent calyx with 5-pointed lobes and with an irregular white corolla of five petals. (Fig. 1.) The claws of the petals are not united nor are they attached to the staminal tube which is formed by the union of the filaments of the nine inferior stamens. As the claws of the alæ and carina are not attached to the staminal tube, the petals may be bent downward sufficiently far so that many different kinds of insects may secure without difficulty the nectar secreted around the base of the ovary.

The fingerlike processes of the alæ are appressed closely to the carina, therefore the alæ are bent downward with the carina by insects. These processes grasp the staminal tube superiorly and tightly when the carina and alæ are in their natural positions, but when the carina is pressed downward by insects the fingerlike processes open slightly but not so far that they do not spring back to their original position when the pressure is removed. The staminal tube splits superiorly to admit the tenth free stamen. The filament of this superior stamen lies along the side of this staminal tube. The filaments of the nine stamens which compose the staminal tube separate in the hollow of the carina. All stamens bear fertile anthers. The pistil is in the staminal tube, the upper part of the style and stigma of which is inclosed with the anthers in the carina. The stigma is slightly above the stamens.

An insect inserts its head into a sweet-clover flower between the vexillum and carina, the stigma, therefore, comes into direct contact with the head of the insect and cross-pollination is effected. At the same time the anthers brush against the insect, so that its head is dusted with pollen, to be carried to other flowers.

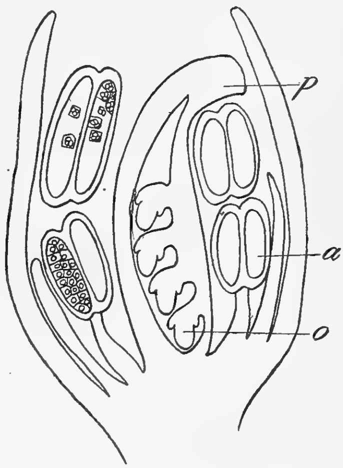


FIG. 2.—Lengthwise sectional view of a very young flower of *Melilotus alba*, showing the relative development of the stamens and pistil. In the upper set of stamens the divisions of the mother cells are completed, while division is just beginning in the lower set of stamens. In the ovules the outer integuments are well started on their development. *a*, Anther; *o*, ovule; *p*., pistil. ×38.

DEVELOPMENT OF THE FLORAL ORGANS OF SWEET CLOVER.

The stamens of *Melilotus alba* and *M. officinalis* may be divided into two sets, according to their length and time of development. (Fig. 2.) The longer set extends about the length of the anthers above the shorter set, and the pollen mother cells in the longer set divide to form pollen grains at least two days earlier than those in the shorter set. At the time the pollen mother cells divide, the longer set of stamens is approximately three-eighths of a millimeter in length and the pistil about half a millimeter long. The stigma and a portion of the style project beyond the stamens, and this relative position is maintained to maturity. The pollen mother cells undergo the reduction division while the megaspore mother cells are just being differentiated and while the outer integuments are barely prominent at the base of the nucellus. The pollen grains are formed while the embryo sac is beginning to develop. The division of the megaspore mother cell does not occur until a number of days later, and the embryo sac is not mature until the flower is nearly ready to open. Thus, the pollen grains are formed a week to 10 days before the embryo sac is ready for fertilization. The pollen grains increase in size and undergo internal changes after their formation. These changes, which are not completed until the flower is one-half or more of its mature length, may be regarded as the ripening processes, and they are undoubtedly necessary before the pollen is capable of functioning. For this reason it is probable that the pollen grains are not able to function much before the embryo sac is mature.

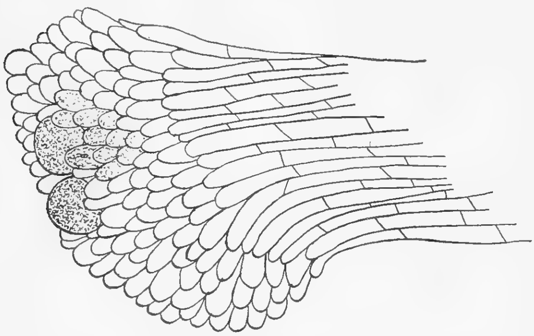


FIG. 3.—Stigma at the time of pollination, showing its papillate character and the position of the pollen in reference to the papillæ in pollination. ×175.

The pistils of *Melilotus alba* and *M. officinalis* are straight for the greater part of their length, but curve rather abruptly toward the keel just below the capitate stigma. The surface of the stigma is papillate. (Fig. 3.) In their reaction with Sudan III, alkanin, and safranin the walls of the papillæ of the stigma show that some fatlike substances are present. Aside from water, the contents of the papillæ consist chiefly of a fine emulsion of oil.

DEVELOPMENT OF THE OVULES.

The number of ovules in the ovary of *Melilotus alba* varies from two to five; however, most commonly, three or four ovules occur. In *Melilotus officinalis* the number in each ovary ranges from three to six. In both species the ovules are campylotropous at maturity with the micropylar end turned toward the base of the ovary.

Mature ovules contain two integuments, but the inner one does not close entirely around the end of the nucellus. The outer integument develops considerably ahead of the inner one. The outer integument is much thickened at the micropylar end, the seed coat is formed from it, and the inner integument is used as nourishment by the endosperm and embryo.

The number of megaspore mother cells in an ovule varies from one to many. Two or more embryo sacs often start to develop in the same ovule, but seldom more than one matures. (Pl. I, figs. 1, 2, and 3.) In general, the development of the embryo sac proceeds in the ordinary way, as described by Young (44, p. 133), with the inner megaspore functioning. (Text fig. 4 and Pl. II, fig. 1.) In its development the nucellus is destroyed rapidly, the destruction being most rapid first at the micropylar end proceeding backward. The nucellus is completely destroyed at the micropylar end by the time the embryo sac is mature, and consequently the embryo sac comes in contact with the outer integument in this region. (Pl. II, fig. 1.) As the destruction of the nucellus extends toward the chalazal end the embryo sac becomes much elongated and tubelike. The antipodals disappear early, so that a mature embryo sac consists of the egg, the synergids, and the two polars. The two polars lie in contact in the micropylar end of the sac near the egg until fertilization.

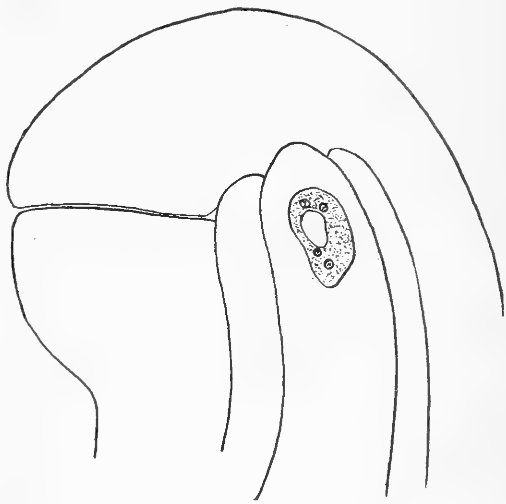


FIG. 4.—Median section through an ovule, showing the embryo sac with four nuclei and the position of the integuments. ×150.

STERILITY OF THE OVULES.

In *Melilotus alba* and *M. officinalis* there is very little tendency toward sterility of ovules. In an extended study of ovules developing under normal and under excessive moisture conditions only an occasional one was found in which no reproductive cells were differentiated, and no ovaries were found in which all of the ovules were sterile.

DEVELOPMENT OF THE POLLEN.

The pollen mother cells do not separate, but previous to the reduction division the protoplasm shrinks from the walls, thus forming a dense globular mass which often occupies less than half the lumen of the mother cell. (Pl. I, fig. 4.) Nuclear division occurs while they are in this contracted condition, and four nuclei are formed from two successive divisions. The cytoplasm is equally distributed around each nucleus. The four masses of protoplasm separate, and as they enlarge a number of times and develop into mature pollen grains they become binucleate, and a wall is gradually formed around each. (Pl. I, figs. 5 and 6.) At first the cytoplasm is quite dense and contains some starch but no fatty oils. However, the cytoplasm of mature pollen grains is vacuolate, and it contains a fatty oil in the form of an emulsion. Soon after the pollen grains are formed, the walls of the mother cells disappear, thus permitting the pollen grains to lie loose in the anther.

FERTILIZATION IN MELILOTUS ALBA.

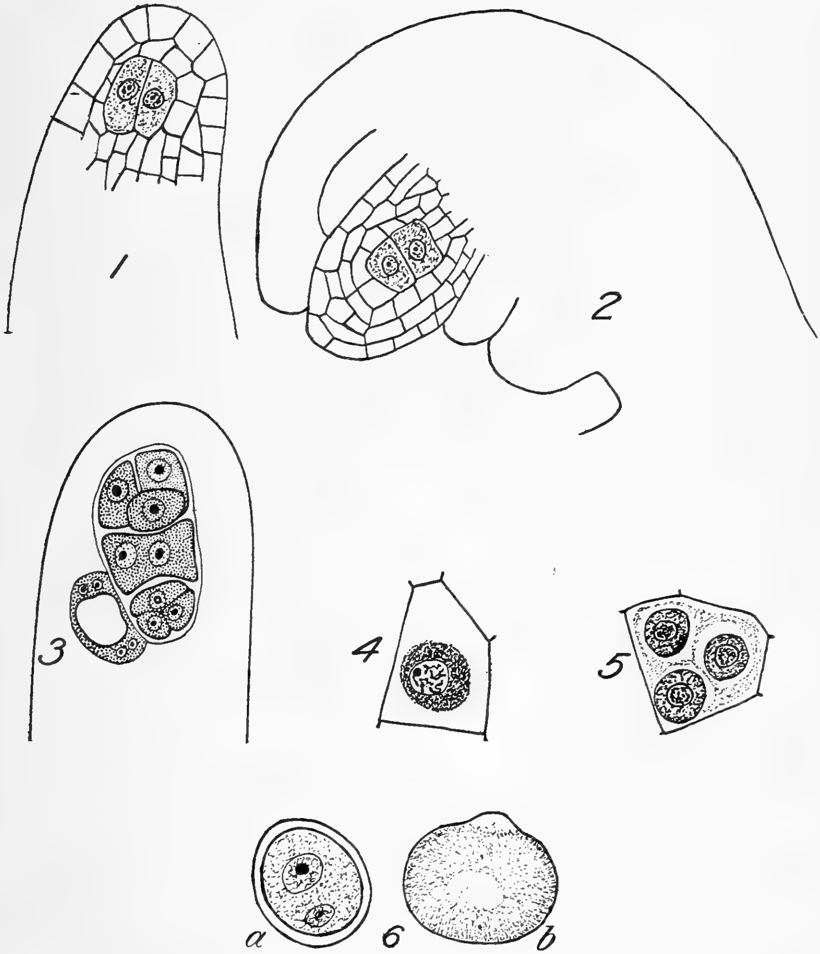
The time intervening between pollination and fertilization was investigated with both self-pollinated and cross-pollinated flowers. In cross-pollination the parents were separate plants. This point was investigated with plants out of doors during the summer of 1916 and with plants in the greenhouse during the following winter. The time elapsing between pollination and fertilization ranged from 50 to 55 hours and was not longer in the case of self-pollinated than with cross-pollinated flowers. Furthermore, the rate of the development of the embryo in each kind of pollination was studied and was found to be as rapid in self-pollination as in cross-pollination. Therefore, self-pollination is apparently as effective as cross-pollination in *Melilotus alba* so far as the vigor of pollen tubes and the rate at which embryos develop are concerned. *Melilotus officinalis* was not studied in reference to this point.

Considerable difference often exists in the size of the young embryos in the ovules of the same pod. This is due in part to a difference in the time of fertilization, although some of it is due to a difference in nourishment. It was observed that the ovule first fertilized might be an upper one, lower one, or any one between these. Occasionally one or more ovules are not fertilized.

DEVELOPMENT OF THE SEED.

A proembryo with a rather long suspensor is developed from the fertilized egg. (Pl. II, fig. 2.) The endosperm, which quite early forms a peripheral layer around the entire embryo sac, develops most rapidly about the embryo, which soon becomes thoroughly embedded in it. (Pl. III, figs. 1 and 2.) After the embryo has used up the endosperm in the micropylar end and has enlarged so much as to occupy nearly all of the space in this region, the development of the endosperm becomes more active in the chalazal end, and when the embryo is mature there is very little endosperm left.

The seed coat begins to form about the time of fertilization, although it apparently does not depend upon it, for in ovules where fertilization is prevented the outer integument undergoes the early modifications in the development of the seed coat before the ovule breaks down. The development of the seed coat is apparent first at the micropylar and chalazal ends, where the outer cells of the outer integument become much elongated and their outer walls thicken very soon after fertilization. The modifications in the development



DEVELOPMENT OF THE OVULES AND POLLEN IN SWEET CLOVER.

FIG. 1.—Section through the nucellus of an ovule of *Melilotus alba*, showing two megaspore mother cells. ×360. FIG. 2.—Median section through an ovule of *Melilotus alba*, showing the two cells resulting from the first division of the megaspore mother cell, and the relative development of the different parts of the ovule. ×300. FIG. 3.—Section through the nucellus of an ovule of *Melilotus alba*, showing two embryo sacs, one being more advanced than the other. ×360. FIG. 4.—Protoplasm of the pollen mother cell of *Melilotus alba* contracted and ready to undergo division. ×560. FIG. 5.—Pollen grains of *Melilotus alba* just formed, showing their dense cytoplasm and the presence of the mother-cell wall. ×560. FIG. 6.—*a*, Mature pollen grain of *Melilotus alba*, showing the binucleate condition at the time of shedding; *b*, surface view. ×560.

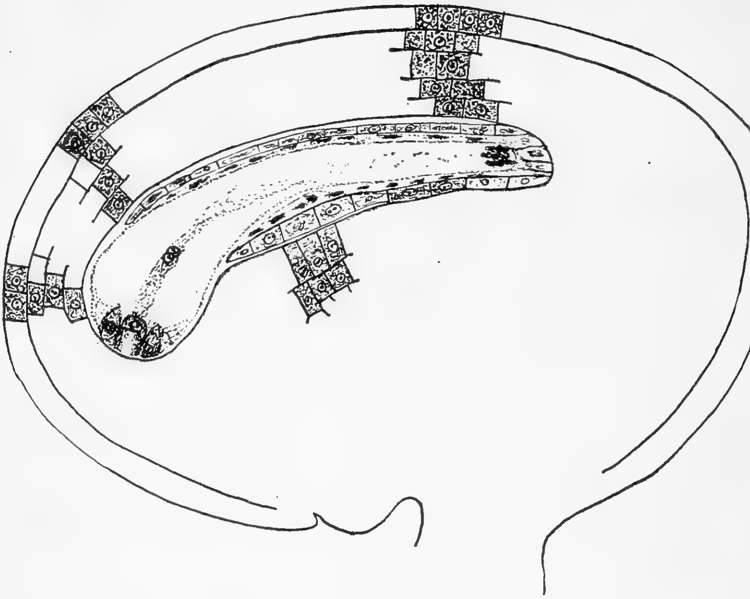


FIG. 1.—MEDIAN SECTION THROUGH AN OVULE OF MELILOTUS ALBA.

The embryo sac is shown ready for fertilization. The egg and synergids are in contact with the outer integument at the micropylar end. The remains of the antipodals may be seen at the chalazal end. ×180.

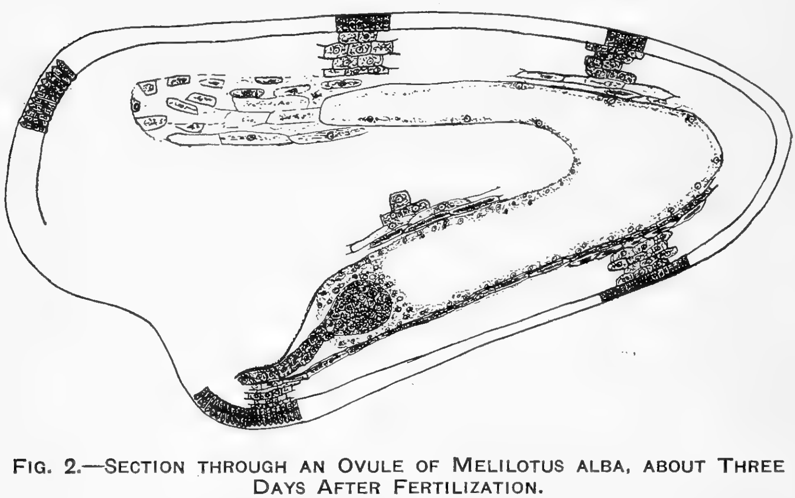


FIG. 2.—SECTION THROUGH AN OVULE OF MELILOTUS ALBA, ABOUT THREE DAYS AFTER FERTILIZATION.

The proembryo, the endosperm, and modifications of the integuments are shown. At this stage the suspensor is a prominent part of the proembryo, and the endosperm is most abundant around the embryo. The inner integument is being rapidly destroyed, and the outer integument is beginning to form the seed coat, as is indicated by the modifications in the outer layer of its cells, which are elongating and thickening their outer walls. ×33.

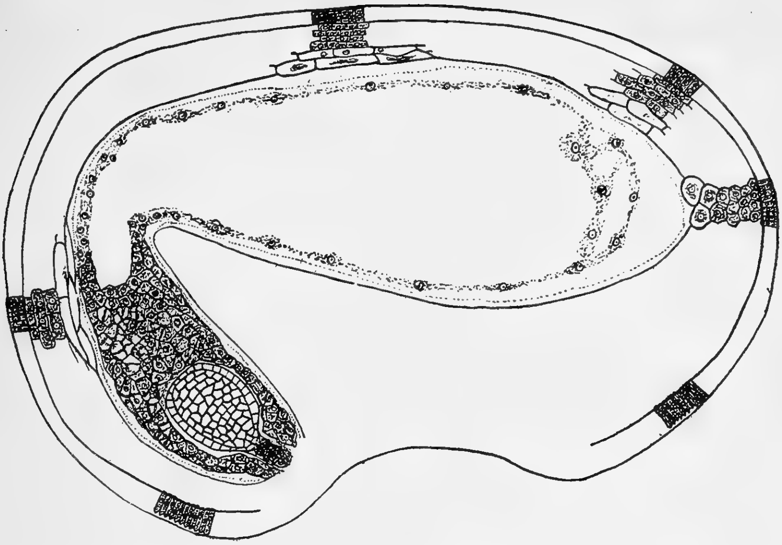


FIG. 1.—SECTION OF AN OVULE OF MELILOTUS ALBA AFTER FERTILIZATION.

The stage of development is a little later than that shown in Plate II, figure 2. The embryo is embedded deeply in endosperm tissue. ×45.

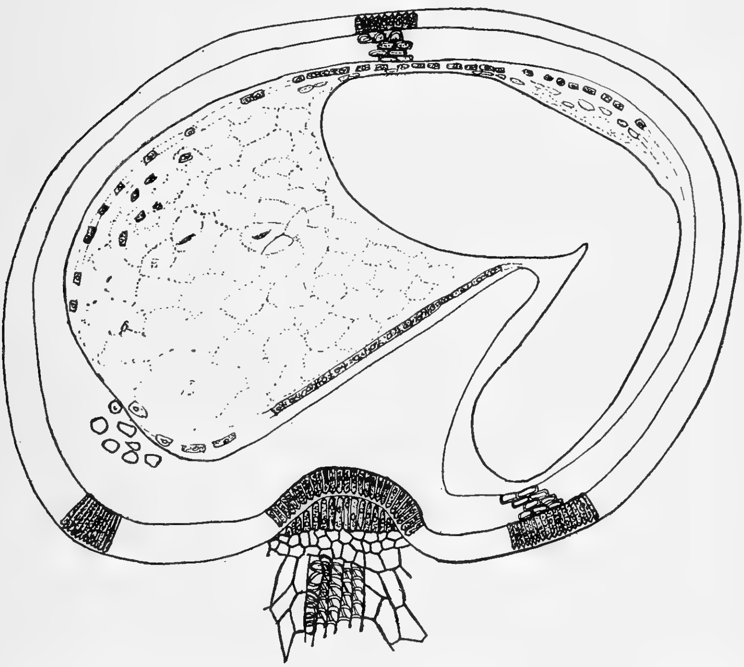
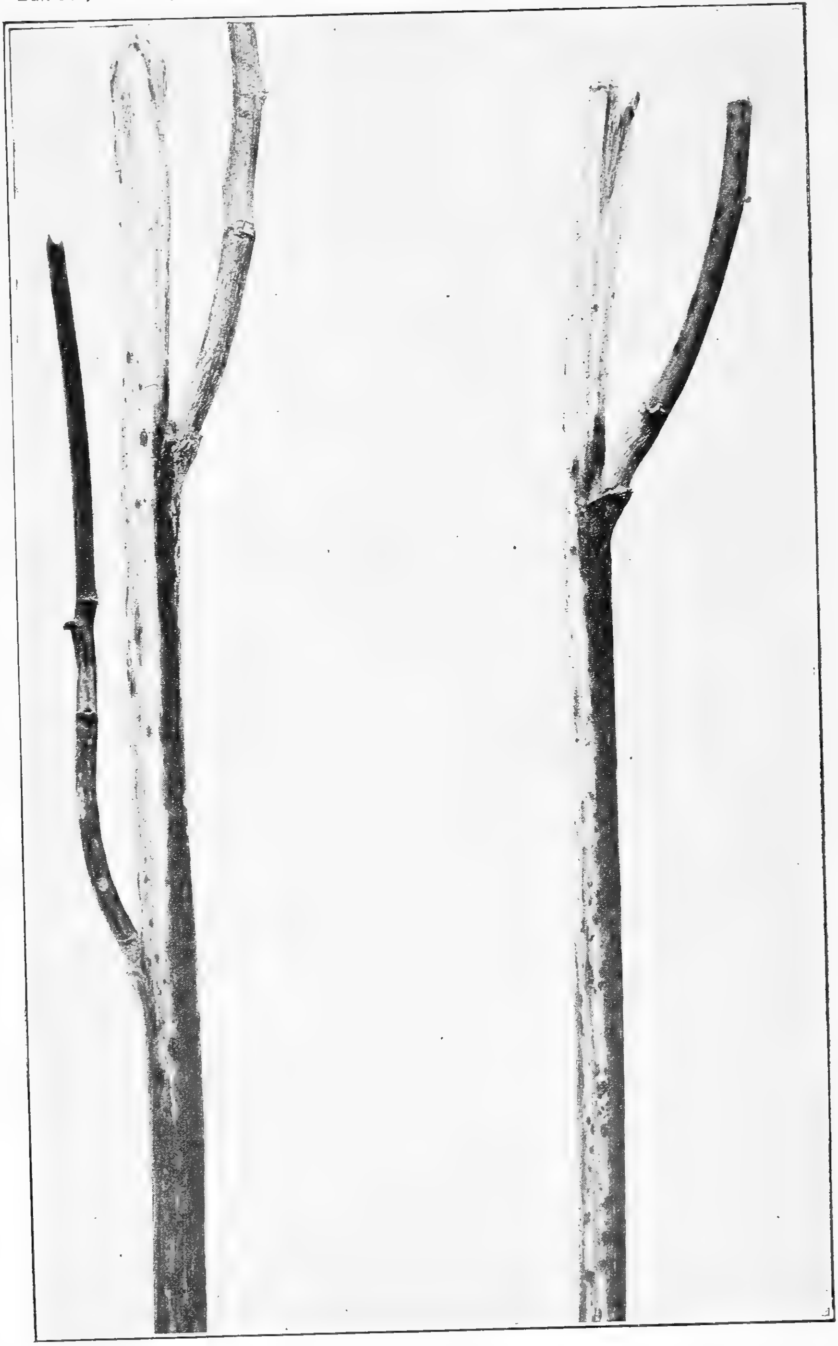


FIG. 2.—SECTION THROUGH AN OVULE OF MELILOTUS ALBA AFTER THE EMBRYO IS NEARLY HALF MATURE.

But little endosperm remains except in the chalazal end, and very little remains of either the nucellus or inner integument. The modifications which transform the outer integument into a seed coat are well under way. Not only the outer layer of cells which becomes the Malpighian layer is quite well modified, but also the layer beneath is being transformed into the osteosclerid layer. ×30.



STUBBLE OF MELILOTUS ALBA.

These plants, which were cut 12 inches above the ground during rainy weather, had made a 40 to 42 inch growth. The stubble became infected at the top and the light-colored portions of them were killed by disease, thus checking the water supply to the growing branches above the infection.

of the seed coat extend around the ovule from these points, involving at first only the outer or epidermal layer of cells which form the malpighian layer. Later, the cells just beneath the malpighian layer form the osteosclerid layer. Accompanying or closely following the formation of the osteosclerid cells, the remaining cell layers of the outer integument become modified into the nutritive and aleurone layer, and the seed coat is fully formed. Meantime the inner integument is practically all used as food.

MATURE POLLEN OF SWEET CLOVER.

The pollen grains of *Melilotus alba* and of *M. officinalis* are quite similar. Each grain contains three germ pores, and when viewed so that the pores are visible they present a slightly angled appearance. The average dimensions of the pollen of *Melilotus alba* and of *M. officinalis* are 26 by 32 microns and 24 by 30 microns, respectively, when measured in the positions shown in *b* in Plate I, figure 6.

The walls of the pollen grains have cutin deposited in them, as shown by their reactions with Sudan III, alkanin, safranin, and chloriodid of zinc. The contents of the pollen grains give a distinct reaction when tested for fat, and Millon's reagent shows that also some protein is present. Tests for sugars and starch showed that these substances are not present in perceptible quantities in mature pollen grains, although some starch is present in immature pollen.

GERMINATION OF THE POLLEN.

The germination of the pollen of *Melilotus alba* permits considerable variation in moisture, as is illustrated in Table I.

TABLE I.—*Germination of the pollen of Melilotus alba in water and in solutions of cane sugar of different strengths.*

Melilotus alba.	Pure water.	Cane sugar in solution (per cent).							
		8	12	18	24	30	35	45	55
Germination of pollen ....per cent..	33	23	64	46	60	46	31	22	0

The results given in Table I represent the average of 12 tests. Some of the pollen grains burst in pure water and in the weak cane sugar solutions, the percentage of bursting being greatest in pure water and decreasing as the percentage of sugar in the solution was increased. There was considerable variation in the percentages of germination in both water and in the solutions of different strengths, and at times there was very little bursting which was not accompanied by a high percentage of germination. The pollen tubes grew as rapidly in water as in any of the sugar solutions, some reaching a length of 100 microns in six hours. As the pollen tubes made no more growth in the solutions of sugar than in water, it is evident that the sugar is not used as food, but helps in germination by reducing the rate at which water is absorbed.

To judge from Table I, the pollen of sweet clover can be effective not only under ordinary conditions but also when the flowers are wet with rain or dew or when the stigma is so dry that in order to obtain water from the papillæ the pollen must overcome a high resistance offered by the sap of the papillæ, a resistance that may be equal to the osmotic pressure of a 45 per cent solution of cane sugar. This is in accord with results obtained under field conditions, as flowers that were pollinated while rain was falling set seed satisfactorily, indicating that a high percentage of humidity in the atmosphere does not check the germination of the pollen sufficiently to interfere with fertilization. Neither was the setting of seed affected when the soil about the roots of plants was kept saturated with water, showing that the excessive quantity of water in the stigmas resulting from an abundance of water in the soil did not interfere with the fertilization of the flowers.

No definite counts were made of the germination of the pollen of *Melilotus officinalis* in the solutions of cane sugar of different strengths, but observations show that the moisture requirement of the pollen of this species is approximately the same as that of *Melilotus alba*.

CROSS-POLLINATION AND SELF-POLLINATION OF SWEET CLOVER.

Results published by previous investigators on the cross-pollination and self-pollination of sweet clover do not agree. The experiments of Darwin (4) show that the flowers are self-pollinated to only a small extent. On the other hand, Kirchner (18) and Kerner (17) find that self-pollination occurs generally and that cross-pollination is not necessary for the production of seed. However, all investigators agree that many different kinds of insects are able to pollinate sweet clover.

Because of the diverse opinions as to the pollination of sweet clover, a number of experiments were conducted to determine (1) whether insect visitation was necessary to pollinate the flowers, (2) if necessary, whether the flowers must be cross-pollinated, and (3) what insects are active agents as pollinators of sweet clover.

ARTIFICIAL MANIPULATION OF SWEET-CLOVER FLOWERS.[1]

Experiments were conducted to determine, if possible, the effect of various types of artificial manipulation of sweet-clover flowers when in full bloom on the production of seed. Only healthy, vigor-

[1] The writers wish to acknowledge their indebtedness to Mr. Carl Kurtzweil for assistance in conducting part of the field experiments at Ames.

ous plants growing on well-drained soil were selected for these experiments. Before any of the flowers were open, the individual racemes were covered with tarlatan and labeled. (Fig. 5.) As soon as part of the flowers opened, the racemes were uncovered and after removing all flowers that were not open the open flowers were pollinated and the racemes re-covered. If the flowers of sweet clover are not fertilized they will remain open for two to three days, then wither, and in a short time drop. But after being fertilized the ovules

FIG. 5.—Individual racemes of white sweet clover covered with cheesecloth to protect them from insect visitation.

enlarge very rapidly, and the corollas usually drop in about seven or eight days. Therefore, all fertilized flowers can be distinguished a few days after fertilization has taken place. Counts were made of the number of pods which formed in 10 to 12 days after pollination. An outline of the experiments is given in Table II.

TABLE II.—*Treatment of sweet-clover flowers in the artificial-manipulation experiments.*

Experiment.	Method of pollinating the flowers.
A	Check—covered.
B	Check—open to insect visitation at all times.
C	A separate toothpick was used to spring the keel of each flower on the raceme.
D	One toothpick was used to spring the keels of all the flowers on a raceme.
E	Cross-pollinated.
F	Raceme rolled several times between thumb and finger.

As insects, and especially honeybees, usually visit all recently opened flowers on a raceme, experiments C and D were conducted to determine whether more seed would be produced when pollen from other flowers on the same raceme was placed on the stigmas of the flowers than when only the pollen produced by each flower was placed on its own stigma. The effect of pollination when only the pollen produced by an individual flower was placed on its own stigmas was also obtained in experiment F, as by this method of pollination no pollen was transferred from one flower to another. It can not be stated definitely that the seed produced by the cross-pollinated flowers was the result of fertilization with foreign pollen, as the anthers were not removed from the flowers pollinated because it would be necessary to remove the anthers when the flowers were not more than two-thirds mature, and in doing this the flowers would be so mutilated that only occasionally would pollination at this time or at a later date be effective. The flowers listed in experiment E were pollinated a short time before they opened, and in each case pollen taken from flowers of other plants was placed on the stigmas. The petals of the cross-pollinated flowers were not mutilated, and in each case they returned to their original positions soon after pollination. The results obtained in experiment B, where the racemes were simply labeled and left open to the action of insects at all times, serve for comparison with other experiments where the flowers were protected from insect visitation and were artificially manipulated.

Martin (25) found the setting of alfalfa seed and Westgate (40) found the setting of red-clover seed to be affected by an excessive quantity of moisture in the soil or atmosphere. In order to overcome the possible effect of this or of other detrimental factors, in each experiment only the flowers on a certain number of racemes were pollinated at one time. All of the experiments were repeated a number of times during the months of July and August, 1916, and the results given in Table III show the total number of flowers pollinated and the number of pods that formed during the two months.

The results presented in Table III show that flowers fertilized with pollen transferred from another plant produced a higher percentage of pods than any of the other treatments. The results obtained in experiment D, where the same toothpick was used to spring the keels of all the flowers on a raceme, show that this method of pollination produced an average of 7.24 pods per raceme more than the racemes in experiment C, where a separate toothpick was used for each flower. These results indicate that pollen transferred from one flower to another on the same raceme is more effective than when the pollen produced by an individual flower is used to fertilize its own stigma. However, the results of experiment C prove that self-pollination is effective in *Melilotus alba*. In experiment B, which was the open check, 4.3 per cent more flowers set seed than on the racemes where the same toothpick was used to spring all the keels, but 11.57 per cent more seed was obtained than in experiment C. Spontaneous self-pollination occurs to only a very small extent, as will be seen from the results of experiment A, in which an average of only 2.9 per cent of the flowers set seed.

TABLE III.—*Effect of different types of artificial manipulation on the seed production of sweet clover at Arlington, Va., and at Ames, Iowa, in 1916.*

Location.	Experiment.	Total number of—			Flowers that set seed (per cent).	
		Racemes.	Flowers.	Pods set.	At each station.	Average.
Arlington	A	49	3,510	144	4.1	2.9
Ames	A	84	4,536	92	2.0	
Arlington	B	100	5,599	3,973	70.95	66.51
Ames	B	196	1,276	600	47.02	
Arlington	C	50	1,229	701	57.03	54.94
Ames	C	75	289	133	46.02	
Arlington	D	50	1,480	936	63.24	62.18
Ames	D	88	575	342	59.47	
Arlington	E	31	377	307	81.43	70.10
Ames	E	48	175	80	45.71	
Arlington	F	30	933	524	56.16	....

SEED PRODUCTION OF MELILOTUS ALBA UNDER ORDINARY FIELD CONDITIONS.

The production of seed of *Melilotus alba* under ordinary field conditions varies considerably, not only in different parts of the country but also on different fields in the same region. A number of factors contribute to this variation, one of the most important of which appears to be the inability of the plant to supply all the developing seed with sufficient moisture, causing some of them to abort. As pointed out on page 22 this condition was very marked in certain parts of the country in 1916. However, poor seed production is not always correlated with lack of moisture, for the seed crop was a failure in 1915, where cloudy and rainy weather prevailed much of the time the plants were in bloom. It is believed that the lack of pollination by insects was the principal cause for the failure of seed to set, as very few insects visit sweet-clover flowers when such conditions prevail. As sweet-clover pollen will germinate in pure water and as plants which have their roots submerged in water set seed abundantly when pollinated, the failure of the seed crop in 1915 was not due to excessive moisture.

As a rule, thin stands of sweet clover produce more seed to the acre than thick stands and isolated plants more seed than those growing in either a thick or thin stand. The correlation of seed production with the thickness of stand is probably due to the shading and partial prevention of insect visitation to part of the racemes on the lower branches. Most of the flowers upon the lower branches of isolated plants are directly exposed to sunlight and to insect visits; therefore the racemes on these branches produce as large a percentage of seed as the racemes on the upper branches. In a thick stand, little seed is produced by racemes on the lower branches.

A plant approximately 3 feet high growing close to the center of a field at Arlington, Va., in which was an average stand of four sweet-clover plants to the square foot was selected in order to determine the number of racemes produced and the average number of seeds to the raceme. This plant produced 196 racemes, which contained an average of 20.4 pods each. The racemes varied from 2 to 10 cm. in length, and the number of pods to the raceme ranged from 0 to 75. The racemes on the upper and most exposed portions of the plants were larger and the flowers produced a much higher percentage of pods than the racemes close to the bases of the larger branches. Many of the small racemes on the lower branches produced less than five pods each.

The data obtained from the two plants at Arlington that were protected from night-flying insects may also be cited here, as the results of that experiment show that night-flying insects are not an important factor in the production of sweet-clover seed, and, further, because they were growing under the same conditions, in the same plat, and were approximately of the same size. These two plants produced a total of 544 racemes, with an average of 20.9 pods each. The number of pods to the raceme varied from 0 to 86.

EFFICIENCY OF CERTAIN KINDS OF INSECTS AS POLLINATORS OF SWEET CLOVER.

In order further to test the self-sterility of sweet clover and to determine the relative efficiency of night-flying and of different kinds of day-flying insects as pollinators of the flowers, a number of cages covered with cheesecloth, glass, or wire screen having 14 meshes to the linear inch were placed over plants at Arlington, Va., and at Ames, Iowa, in July and August, 1916. The bases of the cages were buried several inches in the ground, so that insects could not pass under them. Cheesecloth was used to cover most of the cages and was made into sacks of such a size that they could be put on or removed from the frames of the cages without difficulty. It was stretched tightly over the frames and fastened to their bases with laths.

A cage having two sides and the top of glass but with ends covered with cheesecloth to permit ventilation was used at Ames to protect a number of plants from insect visitation at all times. The purpose of this cage was to determine whether the partial shading of the plants in the cages covered with cheesecloth would have any effect upon the setting of seed.

The cage covered with wire netting having 14 meshes to the linear inch was used to determine the efficiency as pollinators of sweet clover of insects so small that they could pass through openings of this size.

The plants used in the experiments at Arlington were growing close to the center of a field of sweet clover. Volunteer plants in a field that contained only a scattering stand were used at Ames. The cages were placed over the plants in all of these experiments before any of the flowers opened, and the work was continued until they were through blooming.

PLANTS SUBJECT TO INSECT VISITATION AT ALL TIMES.

A plant subject to insect visits at all times and growing in the same plat as those inclosed in the cages at Arlington was selected as a check to those inclosed in the cages during their entire flowering period or for only a portion of it. This plant, which was in bloom at the same time as those inclosed in the cages, produced 196 racemes with an average of 20.4 pods each. As all of the racemes were collected and as those on the lower portions of the plant were smaller than those on the upper branches, the average number of seeds per raceme is much lower than it would have been if only the larger racemes had been collected.

An isolated plant that was subject to insect visits at all times was selected for a check to the cage work conducted at Ames. This was necessary in order to get results that would be comparable with those obtained from the plants inclosed in the cages, as the cage experiments at Ames were conducted with isolated plants. The plant produced 239 racemes, with an average of 41.6 pods.

PLANTS PROTECTED FROM INSECT VISITATION DURING THEIR ENTIRE FLOWERING PERIOD.

On July 3, 1916, a cage 3 feet square and 3½ feet high, covered with cheesecloth, was placed over three sweet-clover plants at Arlington. (Fig. 6.) This cage was not opened until August 3, when practically all of the racemes had passed the flowering stage and the few seeds that formed on some of them were practically mature. The three plants inclosed in the cage produced 904 racemes, with an average of 0.63 pod each. No pods were produced on 594 racemes, while 150 produced but one each. None of the racemes produced more than five pods.

This experiment was duplicated at Ames in August, 1916, with the result that the three protected plants produced a total of 776 racemes, with an average of 0.19 pod each.

The plants inclosed at Arlington produced 0.44 pod to the raceme more than the plants inclosed at Ames, and the average for the six plants at Arlington and at Ames is only 0.42 pod to the raceme. Results given below for nine plants inclosed in the glass-covered cage show that the pods produced per raceme by different plants varied from 0.1 to 0.45, which is slightly less than the variation in the two cages covered with cheesecloth.

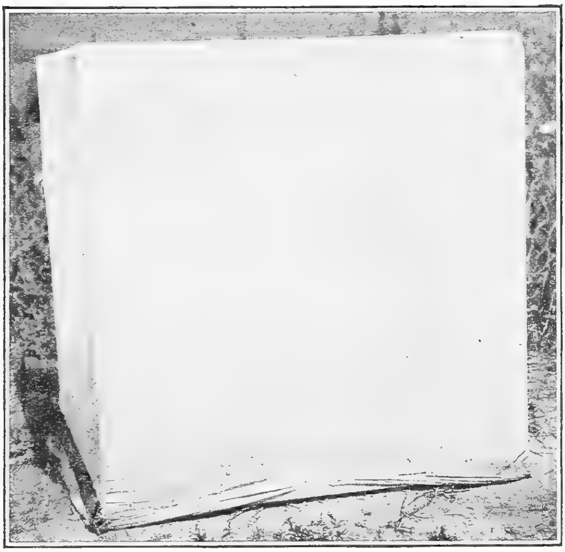


FIG. 6.—Cage covered with cheesecloth to protect plants from insect visitation.

In order to determine whether the shading of the plants in the cheesecloth-covered cages had caused the production of seed to be reduced, a cage 4 feet wide, 4 feet high, and 10 feet long, having glass sides and top, but with ends covered with cheesecloth to permit ventilation, was placed over nine plants at Ames in August, 1916. The results obtained in this experiment are presented in Table IV.

TABLE IV.—*Production of sweet-clover seed by plants protected from insect visitation during their entire flowering period at Ames, Iowa, in 1916.*

Plant.	Racemes per plant.	Pods produced by all racemes.	Average number of pods to the raceme.	Plant.	Racemes per plant.	Pods produced by all racemes.	Average number of pods to the raceme.
No. 1	84	17	0.20	No. 7	119	13	0.10
No. 2	130	58	.44	No. 8	182	83	.45
No. 3	166	30	.18	No. 9	340	142	.41
No. 4	199	88	.44				
No. 5	243	35	.14	Total	1,594	502	
No. 6	131	36	.27	Average			.31

The results given in Table IV show that an average of 0.31 of a pod to the raceme was obtained from 1,594 racemes and that the variation in seed production of the different plants was from 0.1 to 0.45 to the raceme. The average seed production for the nine plants is 0.11 seed to the raceme less than the average results obtained from the six plants that were covered with cheesecloth. As this difference is well within the limit of variation for individual plants, it may be stated that the shading of the plants in the cheesecloth-covered cages did not reduce the production of seed. The results of this experiment show that spontaneous self-pollination does not occur regularly, as stated by Kirchner.

FLOWERS POLLINATED ONLY BY NIGHT-FLYING INSECTS.

In order to determine the importance of night-flying insects as pollinators, two cheesecloth-covered cages 3 feet square and 3½ feet high were placed over sweet-clover plants at Arlington on July 10, 1916. The covers of the cages were removed each evening at 7:30 and replaced each morning at 4:30 o'clock. Practically all the flowers on these plants had bloomed by August 2, and the seed produced was nearly mature. The few racemes that contained opened flowers or buds were discarded. The three plants in one cage produced 723 racemes, with an average of 3.76 pods each, while the one plant in the other cage produced 227 racemes, with an average of 3.58 pods to the raceme. The four plants, therefore, produced a total of 950 racemes, with an average of 3.71 pods each. The only night-flying insect found working on sweet clover while these plants were in bloom was *Diacrisia virginica* Fabr.

This experiment was duplicated at Ames in August, 1916, with the result that one plant subject to visitation only by night-flying insects produced 486 racemes, with an average of 16.5 pods each.

The results obtained in these experiments show that night-flying insects were much more active in pollinating sweet clover at Ames than at Arlington. However, as the results obtained from the plants subject to visitation by day-flying insects only were practically the same as those obtained from plants which were subject to insect visitation at all times, it is concluded that night-flying insects were not a factor in the pollination of sweet clover at Arlington or at Ames in 1916.

FLOWERS POLLINATED ONLY BY DAY-FLYING INSECTS.

A cheesecloth-covered cage, 3 feet square and 3½ feet high, was placed on July 7, 1916, over two sweet-clover plants at Arlington, before any of the flowers opened. As the cover of this cage was removed at 7.30 a. m. and replaced at 4.30 p. m. each day during the experiment, the plants were subject to visitation by day-flying insects only. As soon as all of the flowers on most of the racemes had bloomed, and before any mature pods shattered, the racemes were removed from the plants and the pods produced by each raceme counted. The two plants produced a total of 544 racemes, with an average of 20.9 pods each.

This experiment was also conducted at Ames. One plant was protected from insect visitation at night in August, 1916, with the result that it produced 418 racemes, with an average of 41.11 pods each.

PLANTS PROTECTED FROM ALL INSECTS THAT COULD NOT PASS THROUGH A WIRE SCREEN HAVING 14 MESHES TO THE LINEAR INCH.

It is well known that many small insects, and especially those belonging to the family Syrphidæ and to the genus Halictus, frequent sweet-clover flowers, but no records have been noted that show how important these insects are as pollinators of this plant. In order to obtain data on this subject a cage 12 feet square and 6½ feet high, made of wire screen having 14 meshes to the linear inch, was placed over a few plants at Ames, in July, 1916, before they began to bloom. The base of the cage was buried several inches in the soil, so that no insects could get into it. As these plants were growing in a field where there was a sufficient supply of moisture at all times, they made a growth of 5 to 6 feet. For this reason all the racemes were collected from only a portion of one of the plants instead of from the entire plant, as was done with the smaller ones inclosed in the cheesecloth-covered cages. The branches selected contained 224 racemes, with an average of 24.53 pods each. Many insects that were able to pass through the wire netting were observed working on the flowers of the inclosed plants.

A check plant, subject to visitation by all insects and growing within a few yards of the cage, contained 264 racemes, with an average of 28.23 pods each.

This experiment shows that small insects are efficient pollinators of sweet clover and that the plant to which all insects had access produced an average of only 3.7 pods to the raceme more than the one inclosed in the cage. As these plants were growing close to a strip of timber and some distance from a field of sweet clover, it is probable that more small insects worked on the flowers than would have been the case if the cage had been located in the center of a field of sweet clover. Though these results show that small insects are able to pollinate sweet-clover flowers freely, it is very doubtful whether insects of this kind would be numerous enough to pollinate sufficient flowers in a large field of sweet clover for profitable seed production. The honeybee is the most efficient pollinator of this plant, and it is believed that in many sections it is responsible for the pollination of more than half of the flowers.

SUMMARY OF INSECT-POLLINATION STUDIES.

The data secured in the different experiments where sweet-clover flowers were subject to insect visitation at one time or another are presented in detail in Table V.

TABLE V.—*Summary of the insect pollination studies conducted at Arlington, Va., and Ames, Iowa, in 1916.*

Location.	Number of plants.	Method of treatment.	Number of—		
			Racemes.	Pods produced.	Pods per raceme, average.
Arlington	1	Check—subject to insect visitation at all times.	196	4,013	20.47
Ames	1	.....do	239	9,943	41.60
Arlington	3	Protected from all insects	904	577	.63
Ames	12	.....do	2,370	653	.27
Arlington	3	Visited by night-flying insects only (cage 1).	723	2,720	3.76
Do	1	Visited by night-flying insects only (cage 2).	227	152	.67
Ames	1	Visited by night-flying insects only	486	8,024	16.51
Arlington	2	Visited by day-flying insects only	544	11,397	20.95
Ames	1	.....do	418	17,186	41.11
Do	9	Protected from all insects	1,594	502	.31

The results in Table V show that an average of 0.37 pod to the raceme was obtained from the plants protected from visitation by all insects during the flowering period. As the racemes of *Melilotus alba* will average approximately 50 flowers each, less than 1 per cent of them set seed without being pollinated by insects. The results obtained in the cages in which only night-flying insects had access to the flowers show that these insects pollinate sweet clover to a slight extent, but that the number of pods produced by them is so few that it may be assumed that these flowers would have been pollinated by day-flying insects. This assumption is borne out by the results obtained in the cages where only day-flying insects had access to the flowers, as the results obtained in these cages at Arlington and Ames, respectively, are approximately the same as those obtained on the plants subject to insect visitation at all times. It will be noted that the yield of seed on the plants visited by insects at Ames is much higher than that of the plants subjected to insect visits during the same period at Arlington. This difference in seed yield may be attributed to the fact that isolated plants were used in the experiments at Ames, and at Arlington the experiments were conducted with plants growing under field conditions.

RELATION OF THE POSITION OF THE FLOWERS ON MELILOTUS ALBA PLANTS TO SEED PRODUCTION.

Observations of sweet-clover plants grown under cultivation, and especially when the stands were thick, showed that the flowers of the racemes on the upper and exposed branches produced a larger percentage of seed than those on the lower branches which were less exposed. It is thought by some that the failure of the flowers on the lower racemes to be fertilized is due to shading; but the results obtained in the cheesecloth and glass covered cages do not warrant this belief, as it is doubtful whether the shading of the flowers on the lower racemes is more than that caused by the cheesecloth. It is probably the lack of pollination that causes this decrease in seed production on the lower branches of plants growing close together, as a vast number of flowers open each day on portions of the plants which are exposed directly to visitation by insects and are therefore more accessible to them.

In order to obtain information upon the number of flowers that produce seed on the upper and lower portions, respectively, of sweet-clover plants when grown under field conditions and where the stand contained four to five plants to the square foot, a number of racemes were labeled on different portions of the plants at Ames in 1915 and 1916. When the pods were partly mature, records were made of the number of flowers that produced pods. The results obtained are given in Table VI.

TABLE VI.—*Relation of the position of sweet-clover flowers on the plants to seed production, at Ames, Iowa, in 1915 and 1916.*

Year.	Position of the flowers.	Number of flowers.	Pods formed.		
			Number.	Percentage.	Average.
1915	Upper half of plants	812	357	43.9	42.6
1916	....do	261	101	38.7	
1915	Lower half of plants	344	44	12.7	18.3
1916	....do	216	59	27.3	

The flowers on the upper racemes of the plants produced 31.2 per cent more pods than those on the lower racemes in 1915, and 11.4 per cent more in 1916. These results prove that insects more frequently visit the flowers that are directly exposed and are therefore more accessible.

INFLUENCE OF THE WEATHER AT BLOSSOMING TIME UPON SEED PRODUCTION.

The seed production of sweet clover is seldom satisfactory when rainy or muggy weather prevails during the flowering period. In order to obtain data as to the relation existing between the visits of insects and the prevailing weather conditions, a record of insect visits and of the number of flowers that opened each day was kept for a period of nine days at Ames in August, 1915.

In this experiment the racemes were marked early each morning just above the last flowers which had opened the previous day, and early the following morning the number of flowers which had opened the previous day was noted. The number of flowers that were pollinated was determined by the number of pods that formed. Table VII gives in detail the results obtained.

TABLE VII.—*Influence of the weather at blossoming time upon the yield of sweet-clover seed, at Ames, Iowa, in 1915.*

Date, 1915.	Weather conditions.	Insect visitors.	Number of flowers that opened.	Pods formed.	Percentage of flowers that matured.
Aug. 16	Cloudy and showery	Very few	102	18	17.6
Aug. 17	Rain all day	None	69	4	5.7
Aug. 18	Cloudy most of the day	Very few	60	20	33.3
Aug. 19	Clear and cool	Numerous	94	53	56.3
Aug. 20	Mostly clear and warm	do	61	38	62.2
Aug. 21	Clear and warm	do	81	44	54.3
Aug. 22	Partly cloudy and warm	do	181	100	55.2
Aug. 23	do				
Aug. 24	Cloudy till mid-afternoon	Few	37	12	32.4

The data given in Table VII show that the percentage of effective pollination is much higher in clear weather, when insects are active, than in cloudy or rainy weather, when but few insects visit the flowers.

INSECT POLLINATORS OF SWEET CLOVER.

On account of the ease with which the heavy flow of nectar of sweet-clover flowers may be obtained many insects visit the flowers, thereby pollinating them. While the useful insect visitors of flowers of red clover are limited to a few species of Hymenoptera, those pollinating sweet-clover blossoms are many and belong to such orders as Coleoptera, Lepidoptera, and Diptera, as well as to the Hymenoptera. However, in the United States the honeybee is the most important pollinator of sweet clover. In many parts of the country the different species of Halictus, commonly known as sweat bees, rank next in importance. The margined soldier beetles (*Chauliognathus marginatus* Fabr.) were very active pollinators at Arlington, Va., in the latter part of June and first part of July, 1916, but the woolly bear (*Diacrisia virginica* Fabr.) was the only night-flying insect found working on sweet clover at Arlington.

Insects belonging to the genera Halictus, Syritta, and Paragus were very active pollinators at Ames, Iowa, in 1916, and ranked next in importance to the honeybee. In fact, the results obtained in the cage where the plants were protected from visitation by insects that could not pass through a screen having 14 meshes to the linear inch showed that these small insects were able under the conditions of that experiment to pollinate practically as many flowers as larger insects.

The insects listed below were collected while visiting *Melilotus alba* and *M. officinalis* flowers in 1916.

AT ARLINGTON, VA.

Neuroptera.—*Perithemis domitia* Dru., *Enallagma* sp.

Hemiptera.—*Adelphocoris rapidus* Say, *Lygus pratensis* Linn. (tarnished plant bug).

Coleoptera.—*Chauliognathus marginatus* Fabr. (margined soldier beetle), *Diabrotica 12-punctata* Oliv. (southern corn rootworm).

Lepidoptera.—*Pieris protodice* Bd. (imported cabbage butterfly), *Heodes hypophleas* Bd., *Lycaena comyntas* Gdt., *Hylephila campestris* Bd., *Scepsis fulvicollis* Hubn., *Ancyloxypha numitor* Fabr., *Pholisora catullus* Fabr., *Pyraustid* sp., *Loxostege similalis* Gn. (garden webworm), *Thecla melinus* Hubn., *Colias philodice* Gdt. (the common sulphur butterfly), *Tarachidia caudefactor* Hubn., *Pyrameis atalanta* Linn., Drasteria (2 species), *Diacrisia virginica* Fabr. (the woolly bear).

Hymenoptera.—*Halictus lerouxi* Lep., *H. provancheri* (sweat bee), *H. pectoralis* Sm. (sweat bee), Halictus (3 unidentified species), *H. legatus* Say, *Bombus affinis* Cr., *B. impatiens* Harris (bumblebee), *Melissodes bimaculata* Lep., *Polistes pallipes* Lep. (paper wasp), *Megachile* sp. (leaf-cutter bee), *Coelioxys octodentata* Say, *Xylocopa virginica* Drury (common carpenter bee), *Pompiloides* sp., *Apis mellifica* Linn. (honeybee), *Philanthus punctatus* Say, *Sphex nigricans* Dahlb. (caterpillar hawk), *S. pictipennis* Walsh (caterpillar hawk).

Diptera.—*Archytas analis* Fabr., *Chrysomyia macellaria* Fabr. (screw-worm fly), *Pollenia rudis* Fabr. (cluster fly), *Ocyptera carolinae* Desv., *Trichophora ruficauda* V. D. W., *Eristalis arbustorum* Linn., *Physocephala tibialis* Say.

AT AMES, IOWA.

Hemiptera.—*Lygus pratensis* Linn., *Adelphocoris rapidus* Say.

Coleoptera.—*Coccinella transversoguttata* Fabr.

Lepidoptera.—*Eurymus eurytheme* Bdv., *Chrysophanus* sp., Lycaena (2 species), *Libythea bachmani* Kirtland, *Pieris rapae* Linn.

Hymenoptera.—*Angochlora* sp., *Apis mellifica* Linn., *Colletes* sp., *Halictus lerouxi* Lep., *H. provancheri* D. J., *Halictus* sp., *Elis* sp., *Calliopsis andreniformis* Smith, *Polistes* sp., *Sphex* sp., *Eumenes fraterna* Say, *Sceliphron* sp., *Isodontia harrisi* Fern., *Cerceris* sp., *Oxybelus* sp.

Diptera.—*Syritta* sp., *Paragus* sp., *Chrysomyia macellaria* Desv., Syrphidæ (2 unidentified specimens).

EFFECT OF MOISTURE UPON THE PRODUCTION OF MELILOTUS ALBA SEED.

Careful inspection of a number of sweet-clover fields in Iowa and Illinois in the autumn of 1916 indicated that many plants were unable to obtain sufficient moisture for the proper development of their flowers. Examination of flowers that aborted shortly after reaching their mature size showed that the anther sacs had not burst, even though the pollen grains were mature. Apparently for the same reason many immature pods aborted. The precipitation for July, 1916, in Livingston County, Ill., where the sweet-clover seed crop suffered materially for lack of moisture, was 3.2 inches less than normal, while the temperature was 4.5° F. above normal. In August the precipitation was 0.96 of an inch below normal and the temperature 4.2° F. above normal. At Ames, Iowa, the precipitation was 3.54 inches below normal and the temperature 5.4° F. above normal in July. Both the precipitation and temperature were about normal at Ames in August, but most of the precipitation fell before the experiments were commenced.

In north-central Illinois the seed production of sweet clover was very irregular. Some fields produced an abundance of seed, while a large percentage of the pods on the plants in other fields near by, where the thickness of the stand, size of the plants, and conditions in general were approximately the same, aborted. It was evident that all stands producing a good seed crop were growing on well-drained soil and that those which were not yielding satisfactorily were on poorly drained land. It is well known that sweet clover will produce deep taproots only when the plants are growing in well-drained soil and that a much-branched surface root system will be formed on poorly drained land, and especially when there is an excess of moisture or a high water table during the first season's growth. During this droughty period in 1916 the upper layer of soil became so depleted of moisture that the plants with surface root systems were unable to obtain sufficient water to mature their seed. On the other hand, the lack of precipitation and the high temperatures did not affect the moisture content of the subsoil sufficiently to interfere with the normal seed production of deep-rooted plants. According to Lutts (22, p. 47) this same condition was found to be true in Ohio in 1916.

As a rule, under droughty conditions the second crop of sweet clover will produce a higher yield of seed than the first crop, as the second growth of the plants is seldom more than half as much as the first, thereby requiring less moisture. However, if showery hot weather prevails when the first crop is cut, the end of each stub is very apt to become infected, usually with a species of Fusarium, which kills all the cortex as far back as the upper bud or young shoot and that part of it on the opposite side of this bud to the bud below. If the second bud from the top of a stub is not directly opposite the upper one the decay may extend nearly to the ground. (Pl. IV.) The destruction of half to two-thirds of the cortex from 2 to 4 inches below the upper bud materially reduces the quantity of water that can be conveyed to the branch above the base of the dead area. Plants thus infected obtain sufficient moisture for seed production only under the most favorable conditions. When the first crop is cut during warm dry weather, and especially when the first crop has not been permitted to make more than a 30 to 32 inch growth, the stubble seldom decays, and in no instance have the plants been observed to decay as far back as the upper buds.

An experiment was conducted at Ames in the latter part of August and first part of September, 1916, to determine the effect of watering plants that were aborting a large percentage of their flowers and immature pods. For this purpose several volunteer plants growing in a meadow were selected. A hole 12 inches square and 14 inches deep was dug 8 inches from the crown of one plant, and each evening during the experiment 2 gallons of water were poured into the hole. The top of the hole was kept covered, so as to check evaporation from it as much as possible. Another plant of the same size and growing about 15 yards from the watered plant served as a check. On both plants many of the flowers and immature buds were aborting at the beginning of the experiment. The soil in this field was so depleted of moisture that the leaves of the plants wilted during the hottest part of the days preceding the experiment. The foliage on the check plant wilted each day for the first five days of the experiment. On the sixth day 0.96 of an inch of rain fell and four days later 0.23 of an inch more. The dropping of the flowers was temporarily checked by these precipitations, but owing to the dry, compact condition of the soil the rain was not sufficient to check entirely the fall of flowers and immature pods. At the beginning of the experiment the racemes on both plants were divided into three classes, according to the development of the flowers, and labeled. They were collected and the seeds counted as soon as the pods at the bases of the racemes commenced to turn brown. Table VIII presents the results obtained.

TABLE VIII.—*Effect of water upon the seed production of sweet clover when growing under droughty conditions at Ames, Iowa, in 1916.*

Stage of development when labeled.	Plant not watered.		Plant watered.		Increase from watering.
	Number of racemes labeled.	Average number of pods per raceme that matured.	Number of racemes labeled.	Average number of pods per raceme that matured.	
Flowers at the base of the racemes just ready to open	49	27.39	110	55.63	28.24
Pods 3 to 6 days old	30	21.13	112	39.81	18.68
Pods 9 to 12 days old	35	15.23	50	29.86	14.63

The effect of the water was noticeable soon after the first application, as the leaves and flowers on this plant became turgid and the anther sacs burst at the proper stage of their development. Very few flowers fell after the second day. The water decidedly checked the aborting of immature pods, as is shown by the results obtained on the racemes which were labeled after the pods had formed. The racemes which contained pods 3 to 6 days old when labeled matured 9.95 pods to the raceme more than those which contained older pods at the beginning of the experiment, but this was expected, as most of the aborting which caused this difference had taken place before the racemes were labeled. As very few pods aborted before they were 3 to 6 days old, the difference of 9.95 pods to the raceme in favor of the ones labeled when the flowers at their bases were just ready to open was largely due to the dropping of the flowers on the older racemes before the experiment was begun.

It will be seen that the production of mature pods on the plant not watered was much greater on the racemes that were labeled before the flowers opened than on the older racemes. This difference is undoubtedly due to the precipitation which fell on the sixth and tenth days of the experiment. It is believed that the yield of 15.23 pods to the raceme on the ones labeled when the pods were 9 to 12 days old is representative of the production of pods per raceme previous to the precipitation and that the other racemes on this plant would have yielded proportionately if conditions had remained the same.

In the early spring of 1916, *Melilotus alba* was planted in several large pots in the greenhouse of the Department of Agriculture at Washington, D. C. These pots were placed outside the greenhouse in the late spring, where they remained until the following January, when they were taken into the greenhouse. The plants grew rapidly and began to flower during the latter part of April, 1917. At this time two pots were placed in a large cage made of screen having 20 meshes to the linear inch. One pot was submerged in a tub of water, so that the soil was saturated at all times, while the plant in the other pot was given only sufficient water to keep it from wilting. The pods on a few racemes were self-pollinated and the results obtained are given in Table IX.

TABLE IX.—*Effect of moisture on the seed production of Melilotus alba at Washington, D. C., in 1917.*

Soil treatment.	Total number of—			Flowers that matured (per cent).	
	Racemes.	Flowers.	Pods formed.	Total.	Increase.
Soil given only a limited quantity of water	12	227	65	28.63	....
Soil saturated	17	425	234	55.05	26.22

The results of this experiment compare favorably with those obtained under field conditions at Ames in 1916.

Part II.—STRUCTURE AND CHEMICAL NATURE OF THE SEED COAT AND ITS RELATION TO IMPERMEABLE SEEDS OF SWEET CLOVER.[1]

HISTORICAL SUMMARY.

When agriculturists first began to cultivate wild legumes they observed that many seeds would not germinate within a comparatively short time after planting. Thus the problem of impermeable seeds began to demand attention many years ago. However, impermeable seeds are not confined to the Leguminosæ, as they occur also in the Malvaceæ, Chenopodiaceæ, Convolvulaceæ, Cannaceæ, and other families.

Since the first account of the structure of legume seed coats by Malpighi (23 v. 1) in 1687, many investigators have contributed to our knowledge of the structure of the coats of seeds belonging to this family.

Pammel (31) made an extensive study of legume seeds, including all the genera in the sixth edition of Gray's Manual, as well as genera not included in that publication. He found that the seed coat uniformly consisted of three layers, namely, the outer layer of Malpighian cells, the osteosclerid layer, and the inner layer of nutrient cells. Pammel's work included a study of the seed coats of *Melilotus alba* and *M. officinalis*, and the descriptions and illustrations in his publication agree for the most part with the results obtained in the investigations reported in this article. However, more variation was noticed in the different layers of the seed coat than he describes.

The cause of impermeability in seeds has been investigated by many. It has been found to be due to the embryos in some seeds, such as the hawthorns, but in most cases to the structure of the seed coat, and especially so in the Leguminosæ. Crocker (3) states that, exactly opposite to the common view, the cause of delayed germination generally lies in the seed coats rather than in the embryos. Nobbe (29) thought that the hardness of leguminous seeds was due to the Malpighian layer, and in a later publication Nobbe and Haenlein (30, p. 81) state that the absorbent power of many seeds is inhibited or entirely arrested by the cones of the Malpighian cells and the shields built up between them, which consist principally of cutin. Huss (15) agrees with Nobbe and Haenlein. Verschaffelt (39) found that the impermeability of the seeds of Cæsalpiniaceæ and Mimosaceæ investigated was due to the inability of water to pass through the canals of the seed coat. By soaking the seeds in alcohol or other substances which change the capillarity of the pores, the seed

[1] The writers wish to acknowledge the service rendered by Mr. H. S. Doty, Instructor in Botany, Iowa State College, Ames, Iowa, in assisting in the preparation of this article.

coats were made readily permeable to water. Gola (6) states that the cause of the impermeability of seeds is the peculiar character of the Malpighian cells, which prevents their infiltration and consequent increase in volume, while Bergtheil and Day (2) found that the hardness of the seeds of *Indigofera arrecta* was due to their possession of a very thin outer covering of a substance resistant to water. Ewart (5, p. 185) believes that in most impermeable seeds the cuticle prohibits the absorption of water, but gives as an exception *Adansonia digitata*, in which the whole integument seems to be permeable to water with difficulty. The following is quoted from White (42, p. 205):

> As a general rule in small and medium-sized seeds the cuticle is well developed and represents the impermeable part of the seed coat, while in the cases of large seeds, such as those of *Adansonia gregorii*, *Mucuna gigantea*, *Wistaria maideniana*, and *Guilandina bonducella*, the cuticle is relatively unimportant and inconspicuous. In these seeds the extreme resistance which they exhibit appears to be located in the palisade cells.

In discussing the seed coat of *Melilotus alba*, Rees (33, p. 404) states that the outer layer consists of palisade cells covered externally by a structureless membrane, which, however, did not appear to be cuticle but hemicellulose, as it stained magenta with chloriodid of zinc. The greater part of the walls of the palisade cells also appears to be composed of hemicellulose and the outer ends only were cuticularized. In order to find whether the outer membrane was in itself impermeable to water, this author treated seeds for short intervals in sulphuric acid to dissolve the outside covering without directly affecting the palisade cells. Seeds treated in this manner swelled in water and microscopic examination showed that the ends of the palisade cells were quite intact, but had separated from each other. From this it was concluded that the outer membrane is instrumental in conferring impermeability on the seed, although not directly responsible for it, as is the case with a true cuticle. It is further believed that it probably served as a cement substance by means of which the cuticularized ends of the cells were held together closely, thus forming a barrier through which water could not penetrate, but that as soon as this barrier was removed the ends of the palisade cells separated and water passed in between them.

More than 20 years ago machines were devised by Kuntze, Michalowski (27, p. 86), Huss (15), and later by Hughes (14), to scarify impermeable seeds. Other methods have been recommended and employed to some extent for hastening the germination of seeds. Hiltner (13, p. 44) treated seeds of red clover, white clover, and alfalfa 10, 30, and 60 minutes with concentrated sulphuric acid and found that the best germination resulted from the 60-minute treatment. Love and Leighty (21) also treated the seeds of various legumes with concentrated sulphuric acid and obtained a better germination in all cases. In their investigations with *Melilotus alba* it was found that a 2-hour treatment resulted in some injury to the seed, but that a treatment varying from 25 minutes to 1 hour gave good results. In most cases in our investigations the seed coats of sweet clover became permeable to water after a treatment of 15 minutes in concentrated sulphuric acid, and within 5 minutes all of the Malpighian cells were destroyed down to the light line. Harrington (10) found that the soil, season, climate, color, or size of red-clover seeds had no influence upon the percentage of impermeable seeds and that the good germination ordinarily obtained with red clover was due to the scarifying of the seed coats by the rasps of hulling machines. Harrington (11) also studied the agricultural value of impermeable seeds and found that alternations of temperature cause the softening and germinating of many impermeable clover seeds when a temperature of 10° C. or cooler is used in alternation with a temperature of 20° C. or warmer and that the effect of such an alternation of temperature is greatly increased by previously exposing the seeds to germinating conditions at a temperature of 10° C. or cooler and is decreased by previously exposing the seeds to germinating conditions at a temperature of 30° C. It is a well-known fact that impermeable seeds which remain in the field over winter germinate readily the following spring.

The light line is the most important and interesting feature of the Malpighian cell, at least so far as *Melilotus alba* and *M. officinalis* are concerned. But one light line occurs in the Malpighian cells in most Leguminosæ, although Pammel (32) reports two well-developed light lines in *Gymnocladus canadensis*, Junowicz (16) found three in *Lupinus varius*, and Sempolowski (36) two in *Lupinus angustifolius*.

Many investigators have studied the light line, and different theories have been advanced as to its function, physical properties, and chemical nature. Schleiden and Vogel (35, p. 26) in describing the mature testa of *Schizolobium excelsum* in 1838 undoubtedly referred to the light line when they stated that the walls of the Malpighian cells were not equally thickened. Mettenius (26), in 1846, was probably the first definitely to describe the light line. This author believed it was composed of pore canals, all appearing at the same height in the cells, but he was unable to prove this by cross sections. Lohde (20) studied the light line in seeds of *Hibiscus trionum* and found it cutinized. Hanstein (8) states that the Malpighian cells are composed of two cell layers and the light line is produced by the adjoining walls of the ends of the cells. Later, this same author (9), according to Harz (12), refers to the light line as a perforated disk composed of tissue of strong refracting power.

Russow (34) concludes that the light line is produced by neither chemical nor mechanical changes but is caused by a modified molecular structure containing less water than the remainder of the cell wall. Hiltner (13) agrees with Russow's explanation. Harz (12, p. 561) also agrees with Russow and adds that he has observed that the light line disappeared in a number of cases after applications of nitric acid. Wigand and Dennert (43) suggested that the light line is due to a series of erect fissures, while Tietz (37, p. 32) believes it is due to a chemical modification and that the phenomenon results from the exceptionally extreme density of parts of the cellulose membrane. Junowicz (16) found evidence of cellulose material. The cell wall at this point was strongly refractive and had a different molecular structure. After studying *Phaseolus vulgaris*, Haberlandt (7, p. 38) agrees with the Russow explanation. In the seed of this plant the light line colored blue after being treated with chloriodid of zinc. Sempolowski (36), who investigated the light line in *Lupinus angustifolius*, states that there is not only a difference in the molecular structure but also a chemical modification of the cell wall at this point, since with iodin and sulphuric acid the cell wall colored blue, whereas the light line colored yellow. Wettstein (41), who studied seeds of Nelumbo, agrees with Russow (34) and Sempolowski (36) that chemical and physical modifications occur. He found that iodin and sulphuric acid colored the Malpighian cells intensely blue, the light line at first yellowish, and then later it gradually became blue. This reaction may be accelerated by heat. Iodin produced the same effect, and the light line colored blue more rapidly. When treated with a water-withdrawing medium the light line was not altered for some time, but finally disappeared with continued application. Cooking for a long time in caustic potash or standing in cold caustic potash caused the cells to swell, while the light line remained uninjured at first but finally disappeared. He also believed that the absence of pore canals in the region of the light line caused it to be more dense.

Nobbe and Haenlein (30) treated sections of seed coats of *Trifolium pratense* with iodin and sulphuric acid and found that the light line colored blue as readily as the thickened ridges that radiate inward from it, but that the outer processes of the palisade cells projecting from the light line toward the cuticle stained dark brown. They also state that various causes work to produce such unusual lusters in the light line, the principle one of which is the thickened ridges which radiate inward, reach their greatest development at this point, and coalesce in the lumen of the cell. The result is that the light line falls upon a continuously homogeneous medium, while in the inner portions of the ridges the light passes through media of varying opacity, such as cellulose, water, and protoplasm, whereby it is progressively subdued in varying degrees by partial reflection. Pammel (31, p. 147) studied the light line in *Melilotus alba* and found that it consisted of a narrow but distinct refractive zone below the conical layer. The refractive zone colored blue with chloriodid of zinc. The whole upper part was, however, more or less refractive, while the remainder of the cell wall contained pigment and colored blue with chloriodid of zinc. Small canals project into the walls, in some cases extending beyond the light line.

Beck (1) found that the light-refracting power of the light line was much greater than that of the undifferentiated membrane and stated that there may be in addition to this a chemical difference which can not be detected with the present microchemical methods. He does not believe that it is cuticularized or that it contains less water than the rest of the cell.

Marlière (24, p. 11) gives a physical explanation and states that the true cause of the light line lies in the peculiar structure of the secondary membrane of the Malpighian cell. Tunmann (38, p. 559) observed that it did not hydrolize in weak acids and therefore decided that it was not hemicellulose. He found that it dissolved in concentrated sulphuric acid more readily than the regions surrounding it and that it was composed of pectin or callose. In our investigations the main portion of the light line of *Melilotus alba* and *M. officinalis* was very resistant to concentrated sulphuric acid, only the narrow outer portion being attacked. It showed evidence of callose.

MATERIAL AND METHODS.

Permeable and impermeable seeds [1] of *Melilotus alba* and *M. officinalis* were obtained from commercial samples and also from samples collected in the field. Those selected for sectioning were allowed to dry after being removed from the germinator and then embedded on the ends of pine blocks in glycerin gum, which was made by dissolving 10 grams of powdered gum arabic in 10 c. c. of water and adding 40 drops of glycerin. After the glycerin gum had dried for 24 hours, the seeds were easily sectioned. This method of embedding causes no change in the seed coat. It is more satisfactory than the paraffin method for holding the seeds firmly. The glycerin gum dissolved readily when the sections were mounted in water.

In the microchemical studies Sudan III, alcanin, chlorophyll solution, and phosphoric acid iodin were used to test for cutin or suberin; sulphuric acid and iodin, chloriodid of zinc, and chloriodid of calcium for cellulose; phloroglucin and hydrochloric acid for lignin;

[1] The term "permeable" is used in this paper to designate seeds whose coats are permeable to water in two weeks or less at temperatures favorable for germination, while the term "impermeable" is used to designate seeds whose seed coats are impermeable to water for this length of time when temperatures are favorable for germination. Impermeable seeds are commonly referred to as "hard seeds," and they may become permeable in time.

ruthenium red for pectic substances; and sulphuric acid, Congo red, and aniline blue for callose.

Where very thin sections were necessary for detailed study of the structure of the seed coat, pods in various stages of development were collected, and after the usual preliminary treatment they were embedded in paraffin and sectioned with the microtome. Microchemical tests were made with these sections by using various specific stains. Safranin was used to test for cutin, suberin, and lignin; haematoxylin and methyl blue for cellulose; methylene blue, methyl violet B, mauvein, and ruthenium red for pectic substances; and aniline blue and Congo red for callose. In studying some points with reference to the pore system of the seed coat, it was necessary to use free-hand sections of fresh pods.

In studying the seed coat in relation to the absorption of water, both permeable and impermeable seeds were soaked in water solutions of safranin, gentian violet, eosin, and haematoxylin, then dried and embedded in glycerin gum for sectioning. Seeds were soaked in stains dissolved in 95 per cent alcohol to test the penetration of alcohol. It was evident that the seed coats did not act as a filter, as the stains passed through them with the water or alcohol.

STRUCTURE OF THE SEED COAT.

There is very little endosperm present in mature seeds of *Melilotus alba* or *M. officinalis*. That which is present is quite permeable to water and therefore bears no relation to the impermeable seeds of these plants.

The outer layer of the seed coat, which is the modified epidermal layer of the ovule, is known as the Malpighian layer. (Pl. V, figs. 1 and 2.) The cells constituting this layer, commonly called palisade cells, are the most highly modified cells of the seed coat. They are very much elongated, their length varying in the different regions of the coat, and their outer tangential walls and the outer portions of their radial walls are so much thickened that their lumina are confined to the inner portion of the cells, sometimes occupying less than half the length of the cells. The inner tangential walls and inner portions of the radial walls are thickened just previous to the death of the cells, the thickening sometimes being only slight and sometimes so much as to leave only very narrow lumina.

There is a very thin layer on the outer surface of the Malpighian cells which has been called cuticle by previous investigators, but the chemical composition of this layer and its perviousness to water indicate that there is very little cutin present. This layer is probably the primary epidermal cell wall rather than a deposit on the outer surface of the wall. To determine this a study of the development of the Malpighian cells is necessary.

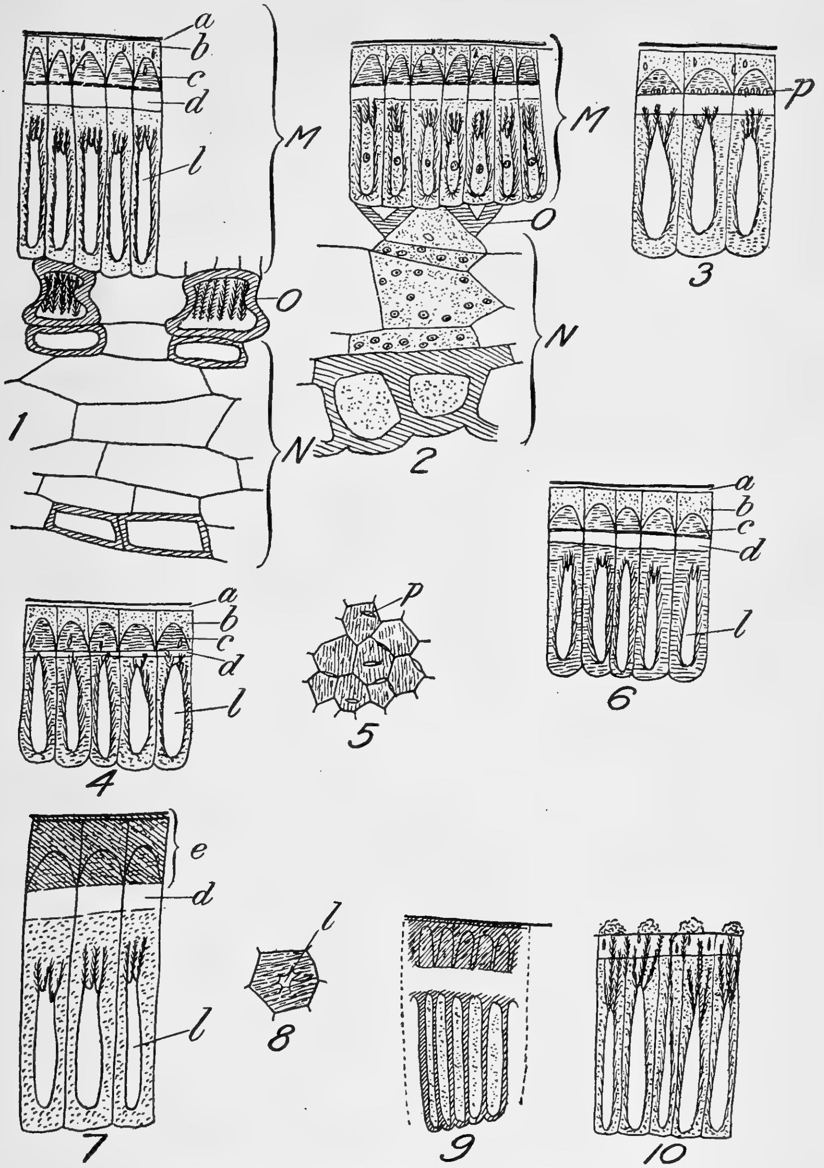
Beneath the so-called cuticle there is the much thickened outer portion of the Malpighian cells in which there are two rather distinct regions, one constituting the conelike structures and the other forming a continous layer over the conelike structures, separating them from the cuticle and filling in between them. These two regions separate easily, and in cutting sections the outer region, called by some the cuticularized portion, often breaks away, leaving the entire surface of the cones exposed.

The term "cuticularized layer" will be used to designate all of the thickening covering the cones, including that around the cones as well as the portion between the cones and the cuticle. This term is not entirely appropriate, for the region is practically free from cutin, but for the want of a better term it will be used. There are canals in the cuticularized layer and cones, which are easily seen when the sections are treated with chloriodid of zinc or sulphuric acid. A surface view of a section showing the cones and cuticularized layer when mounted in glycerin shows the canals as dark lines due to the air inclosed. The canals are most abundant along the lines where the lateral walls of the cells join, but many are within the cones and in the cuticularized substance between the cones. (Pl. V, fig. 5.)

The well-developed light line in *Melilotus alba* and *M. officinalis* is found just below the bases of the cones. In some seed coats only a few and in others none of the canals which are common in the cones and cuticularized region cross the light line. A very distinct line of small canals filled with air and thus forming a dark band is present just above the light line, thus making the light line more conspicuous. (Pl. V, fig. 3.) When the lumina of the cells extend across the light line, they are exceedingly small. The light line is the most compact region of the Malpighian layer and is conspicuous because it refracts the light much more than the regions above and below it.

Just below the Malpighian is a layer of cells variously modified and known as the osteosclerid. The cells of this layer are often referred to as the hourglass cells on account of their shape. In some regions of the seed coat they are expanded at both ends and their walls are much thickened, the thickenings forming ridges on the radial walls, while in other regions only the upper tangential wall and a portion of the radial walls are thickened and the cells are expanded only at the inner end, thus having the shape of the frustum of a cone. Beneath the osteosclerid layer is the nutrient layer.

The nutrient layer contains chloroplasts. It varies not only in the number of layers of cells composing it, but also in the modifications of these cells. This layer ranges from four to seven cells in thickness in the different parts of the seed coat.



STRUCTURE OF THE SEED COAT OF SWEET CLOVER.

FIG. 1.—Section of the seed coat of *Melilotus officinalis*. ×450. FIG. 2.—Another section of the seed coat of *Melilotus officinalis*, showing the variation in size and modifications that occur in the three layers. ×450. FIG. 3.—Section of the Malpighian layer of a *Melilotus alba* seed, showing a line of canals just above the light zone. ×450. FIG. 4.—Section of the Malpighian layer of a permeable *Melilotus alba* seed. ×450. FIG. 5.—Tangential section of the Malpighian cells cut between the cuticle and tops of the cones, showing pores. ×530. FIG. 6.—Section through the Malpighian layer of an impermeable *Melilotus alba* seed. ×450. FIG. 7.—Section through the Malpighian layer of an impermeable *Melilotus alba* seed, showing the region through which water and stains readily passed. ×450. FIG. 8.—Cross section of a Malpighian cell of a permeable *Melilotus alba* seed through the region of the light zone, showing the lumen not entirely closed. ×530. FIG. 9.—Section through the Malpighian layer of a *Melilotus alba* seed shaded to show the portions which react to the cellulose and pectose tests. ×450. FIG. 10.—Section through the Malpighian layer of a *Melilotus alba* seed which shows the condition of the seed coat after 60 minutes' treatment of concentrated sulphuric acid. That portion above the light zone was destroyed, and the lumina as small pores through which much of the stain now passed were seen extending across the light line. The lines between the cells were much more distinct, appearing as small intercellular spaces through which some stain passed. ×450. *a*, Cuticle; *b*, cuticularized layer; *c*, conelike portion of the thickening of the Malpighian cells; *d*, light line; *e*, region of a hard seed coat through which water and stains readily passed; *l*, lumen; *M*, Malpighian cells; *N*, nutrient cells; *O*, osteosclerid cells; *p*, canals just above light zone.

MICROCHEMISTRY OF THE SEED COAT.

Tests for cutin showed that there was very little present in the seed coat. Slight reactions for cutin were observed in the cuticle, in the outer margin of the cuticularized layer, and in the basal portion of the cones. These reactions were so slight as to be almost negligible. It is evident that the cuticle and cuticularized layer are not well named in *Melilotus alba* and *M. officinalis*. Tests for cellulose showed that it was present in the cuticle, cuticularized layer, cones, the walls of the Malpighian cells below the light line, and the walls of the cells of the osteosclerid and nutrient layers. (Pl. V, fig. 9.) The reaction for cellulose in the Malpighian cells was quite distinct in the walls below the light line, less distinct in the cones and cuticle, and least distinct in the cuticularized layer.

Tests for lignin occasionally showed slight traces in the Malpighian cells below the light line. When treated with reagents for pectic substances, the cuticle, cuticularized layer, cones, and all cell walls below the light line gave a definite reaction. The reaction of the cones and cuticle was more pronounced than the cuticularized layer. Tests for callose gave no reaction except in the upper part of the light line. This part of the light line stained slightly blue with aniline blue and was easily dissolved with sulphuric acid. In cutting free-hand sections of fresh material the Malpighian layer sometimes broke along this line. The greater part of the light line reacted to none of the tests, and its chemical nature was not determined.

When microtome sections of seeds in different stages of development were treated with various stains, the results were in accord with those obtained with free-hand sections. Thus with safranin the periphery and cones of the Malpighian cells were slightly stained, while haematoxylin and methyl blue stained all the seed coat except the light line. The cones and cuticle stained more readily than the cuticularized layer, but neither stained as deeply as the cell walls below the light line. Methylene blue, methyl violet B, and mauvein stained all above the light line, indicating the presence of pectic substances; however, the staining was more prominent in the cones and cuticle.

The difference in reaction of the cones and cuticularized layer to the cellulose and pectose tests probably indicates a difference in density rather than a difference in chemical composition. Since the cuticularized layer separates readily from the cones, there may be a difference in physical properties.

With Congo red the upper part of the light line was only very slightly stained, but aniline blue had a more pronounced effect.

The microchemical tests applied to the seed coat show that in the region above the light line there is only a slight trace of cutin or suberin, but a considerable amount of cellulose and pectose. All cell walls below the light line are mainly cellulose but contain some pectose. The upper portion of the light line contains callose, but the remainder of the light line appears to be chemically different from all other parts of the seed coat or else so dense as to resist the attack of the reagents.

THE SEED COAT IN RELATION TO THE ABSORPTION OF WATER.

A study of permeable seeds soaked in water containing stains showed that there were no local regions through which the water passed. The stains passed through all regions of the seed coat. Coating the micropylar region with vaseline retarded germination, but had no effect upon the percentage of germination at the end of three days. In seed coats through which the stain had passed, the light line was not stained. Some stain was found in the canals which crossed the light line, and much more in the cell cavities. There was no evidence that the stain had permeated the substance of the light line. It was able to cross the light line only when pores were present.

In impermeable seeds the stains passed readily to the light line. (Pl. V, fig. 7.) It was evident that the absorption of water was not prevented by either the cuticularized layer or the cone-shaped structures of the Malpighian layer, but by the light line. The region outside of the light line became stained in a few hours, but there was no trace of the stain within the light line after the seeds had remained a week in the stains. Alcohol did not penetrate the seed coat more readily than water.

A COMPARISON OF PERMEABLE AND IMPERMEABLE SEED COATS.

No difference in chemical structure was found between the coats of permeable and impermeable seeds. The principal differences were in the character and amount of thickening of the cell walls.

In many of the permeable seeds some of the canals were found to extend across the light line, but this was not true for all permeable seeds. (Pl. V, fig. 8.) Oblique sections of permeable seed coats showed that the cell cavities, although reduced to mere pores by the thickening of their radial walls, extended across the light line into the base of the cones, thus forming a passageway through which the stains passed to the larger portions of the cell cavities below the light line. (Pl. V, fig. 4.)

In the coats of the impermeable seeds the light line was usually broader, the Malpighian cells thickened more below the light line, and the main cavities of the Malpighian cells were more reduced and farther below the light line than in the coats of permeable seeds. (Pl. V, fig. 6.) No canals except occasionally a few very small ones were seen crossing the light line in impermeable seeds. Cross and oblique sections showed that the lumina of the Malpighian cells were closed in the region of the light line. Thus it was found that permeable and impermeable seeds differ mainly in the amount of thickening which occurs in the walls of the Malpighian cells. In the impermeable seeds the thickening which begins at the outer tangential wall of the Malpighian cell extends farther toward the inner tangential wall, leaving the cell lumina smaller and farther below the light line than in permeable seeds. The thickening is also more complete in impermeable seeds, leaving fewer and smaller canals across the light line as well as closing the cell lumina in the region of the light line.

THE ACTION OF SULPHURIC ACID ON THE COATS OF IMPERMEABLE SEEDS.

Impermeable seeds were soaked in concentrated sulphuric acid (sp. gr. 1.84) for 15, 30, and 60 minutes; then washed and put in the staining solutions. After they had swollen, they were removed from the staining solutions, dried, and embedded in glycerin gum. A study of these seeds showed that the acid had eaten away all of the material outside of the light line and that the stain had passed through all regions of the seed coat. (Pl. V, fig. 10.) When observed under the microscope, it was seen that the action of the acid was rapid, destroying the cuticle, cuticularized layer, and cones in about 5 minutes. After 15 minutes treatment with acid the light line, aside from the presence of canals and pores not previously visible, seemed to be very little affected. The division lines along which the lateral walls of the Malpighian cells were joined now became much more distinct across the light line, thus indicating that there was some swelling in this region. When a close examination of the path of the stain was made the cell lumina, and occasionally very small pores, were found to extend across the light line. The presence of the stain in the pores indicated that they were paths of the stain across the light line. Some of the stain passed along the lines between cells and through the occasional canals crossing the light line, but judging from the intensity of the stain in the lumina the canals appeared to be the principal passageways.

The action of the acid in opening the cell cavities across the light line was not determined. It may be due to the swelling of the light line or to the removal of substances closing the pores.

No seeds were exposed to the acid for longer than an hour, but at the end of this period the light line was still intact. As compared with other portions of the Malpighian layer, it is extremely resistant to concentrated sulphuric acid. Since all cell walls below the light line are mainly cellulose, the resistance of the light line prevents the acid from destroying the entire seed coat and reaching the embryo.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 845

Contribution from the Forest Service
HENRY S. GRAVES, Forester

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PRODUCTION OF LUMBER, LATH, AND SHINGLES IN 1918.

By FRANKLIN H. SMITH and ALBERT H. PIERSON,
Statisticians in Forest Products.

CONTENTS.

INTRODUCTION.

In this bulletin, which is one of an annual series covering the period 1904 to 1918, inclusive, with the exception of 1914,[1] are detailed statistics of the 1918 production of lumber, lath, and shingles in the continental United States,[2] with comparative figures from previous annual reports.

The collection and compilation of the statistics for the Western States were done through the district offices of the Forest Service at Missoula, Denver, Albuquerque, Ogden, San Francisco, and Portland. The figures for New York State were furnished by the New York Conservation Commission.[3] The work in all of the other States east

[1] A detailed summary of the 1914 lumber production is given in Bulletin 506, which contains the figures for 1915.

[2] The production statistics for 1918 were summarized in a preliminary statement issued in May, 1919.

[3] Acknowledgement is made for assistance in the compilation and review of this bulletin to A. B. Strough, New York Conservation Commission; and to C. N. Whitney, Miss Frances R. Waters, Quincy Randles, N. J. Fetherolf, Miss Catherine Deneen, L. A. Nelson, and T. J. Starker, of the Forest Service.

of the Rocky Mountains was done in the Washington office of the Forest Service.

As in former years, the census was carried on in cooperation with the National Lumber Manufacturers' Association, which contributed financial assistance, and aided, through its affiliated organizations, in securing reports from the mills.

TOTAL LUMBER PRODUCTION.

The quantity of lumber reported cut in 1918 by 14,753 mills was 29,362,020,000 board feet. The output of 2,887 mills cutting less than 50,000 board feet each is not included in the total cut. An additional 2,795 mills were reported idle. The estimated total lumber production by 22,546 mills in 1918 was 31,890,494,000 board feet. The reported cut shows a decrease of 11.5 per cent from the 1917 figures; the number of mills reporting, a decrease of 10 per cent; and the estimated total production, a decrease of 11 per cent.

Many of the conditions which were responsible for the slowing up of production in 1917 continued for the greater portion of 1918, and in some instances were accentuated prior to the signing of the armistice in November. War demands of both a direct and indirect character resulted in the taking up of the lumber produced from the usual avenues of utilization.

Ever increasing prices for lumber and other building materials, railroad freight embargoes, car shortages, high wages, and scarcity of labor, curtailed credits, and the discouragement by the Government of all activities other than those aimed to help win the war cut down the demand for lumber for the first 10 months of 1918. Illustrative of building conditions, statistics for the year show the value of construction for which permits were issued in 148 cities of the country to have been approximately $415,000,000, a decrease of 39 per cent from the year before. The decline in 1917 from 1916 was 29 per cent. Conditions at the mills were of a trying character because of the scarcity of skilled labor and the large turnover in both skilled and unskilled labor, increasing costs along every line, and because of the difficulty in making shipments on orders. Export trade remained at a low ebb, for not only was foreign business light but tonnage available was limited. Many small mills did not operate because of unsatisfactory market conditions; 2,795 mills reported idle. The number of big mills operating—those cutting upward of 5,000,000 feet annually—decreased 5 per cent from the year before; the 1,290 mills falling into this classification cut 70.68 per cent of the aggregate output of the country.

The reported lumber cut, the number of active mills reporting, and the estimated annual total cut are given in Table 1 for each year since 1899 for which data have been compiled. The statistics for all of the years are not directly comparable, since the intensiveness of the individual annual canvass made must be taken into consideration. In the enumerations for 1899 and 1909, field agents of the Bureau of the Census were employed, which permitted the output of nearly all, if not all, mills being recorded. The reported cut and the estimated total cut for 1918 are the smallest for any one of the years shown.

LUMBER PRODUCTION BY CLASSES OF MILLS.

As in previous years, the mills were arbitrarily divided into classes according to the quantity reported cut. These classes are shown in Table 2, with the computed[1] number of mills operating and the computed total production for each of the last five years—1914 to 1918, inclusive.

More than two-thirds of the aggregate output of the country's sawmills was produced by 1,290 mills, or but 5.7 per cent of the 22,546, or computed total number, in operation. The concentration of production among the larger operations—mills cutting 10,000,000 feet and over annually—has increased materially during the last decade. In 1909, this class of mills produced 43.09 per cent of the total cut for the year, while in 1918 the same class of mills cut 59.49 per cent of the total. In 1918, the number of class 5 mills operating was about 100 less than for the year before; a number of class 5 mills in 1917 became class 4 mills in 1918 through their cut falling below 10,000,000 feet.

Figures on sawmill capacity with relation to actual production, arranged by classes of mills and by States, are contained in Table 3. The compilation is based upon answers to a question on the lumber cut schedule sent to the mills as to how much lumber the reporting mill could produce in a 10-hour shift if demand and price were very favorable. While not all of the returns contained an answer, the number of replies is sufficiently large to furnish an excellent basis for the table. Local conditions of a wide variety, with climatic conditions dominating, account for the considerable variation in the average number of 10-hour days operated by the mills in different States, and in the average yearly output per mill. The theory held generally by operators that the larger mills, such as those falling into class 5, operate closer to capacity than do the mills in the lower classes is supported by the figures in the tabulation. A computed average figure for the country as a whole is omitted, since there was no logical common basis for it.

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[1] "Computed," as used in this bulletin, expresses results obtained by the extension of figures based on actual returns so as to show totals for approximately all sawmills whether or not reports were received from them.

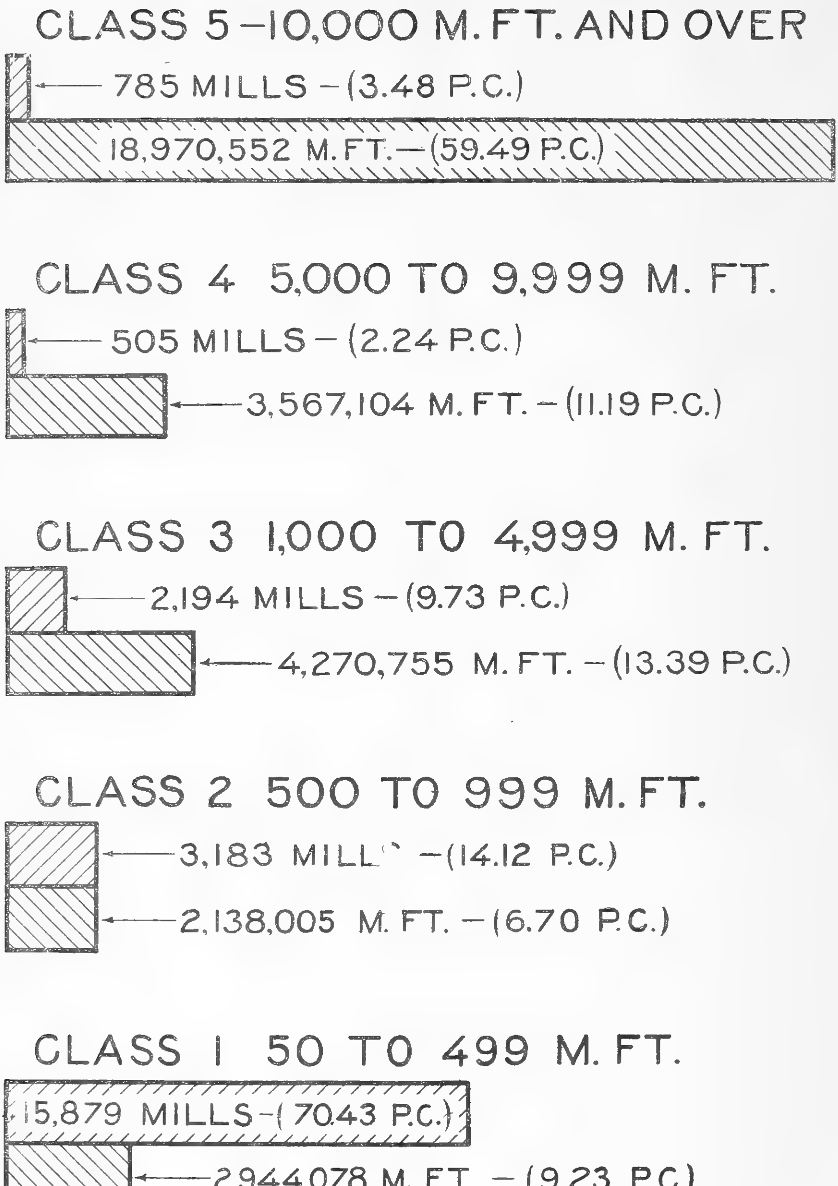

FIG. 1.—Relation of mill classes to production in 1918.

TABLE 1.—*Quantity of lumber reported, number of active sawmills reporting, and estimated total cut, 1899 and 1904–1918.*

Year.	Reported cut of lumber.	Active mills reporting.	Estimated total cut of lumber.
1899	35,084,166,000	31,833	35,084,166,000
1904 [1]	34,135,139,000	[2] 18,277	43,000,000,000
1905	30,502,961,000	11,666	43,500,000,000
1906	37,550,736,000	22,398	46,000,000,000
1907 [3]	40,256,154,000	28,850	46,000,000,000
1908 [3]	33,224,369,000	31,231	42,000,000,000
1909	44,509,761,000	[4] 46,584	44,509,761,000
1910 [3]	40,018,282,000	[2] 31,934	44,500,000,000
1911 [3]	37,003,207,000	[2] 28,107	43,000,000,000
1912	39,158,414,000	[2] 29,005	45,000,000,000
1913	38,387,009,000	[2] 21,668	44,000,000,000
1914 [1]	37,346,023,000	[2] 27,506	40,500,000,000
1915	31,241,734,000	[2] 16,815	38,000,000,000
1916	34,791,385,000	[2] 17,269	40,000,000,000
1917	33,192,911,000	[2] 16,420	36,000,000,000
1918	29,362,020,000	[2] 14,753	32,000,000,000

[1] Custom mills excluded.
[2] Mills cutting under 50,000 feet excluded.
[3] Including mills which manufacture lath and shingles exclusively (1,500 estimated).
[4] Includes 4,543 mills cutting less than 50,000 feet, and all cooperage, veneer, millwork, box, furniture, and other factories cutting any lumber at all in 1909.

TABLE 2.—*Reported production of lumber, 1914, and computed totals, 1915, 1916, 1917, and 1918, by classes of mills.*

Classes.	Year.	Mills.		Computed quantity cut.	
		Computed number operating.	Per cent.	Feet B. M.	Per cent.
All classes	[1] 1914	27,506	100.00	37,346,023,000	100.00
	1915	29,951	100.00	37,011,656,000	100.00
	1916	30,081	100.00	39,807,251,000	100.00
	1917	24,815	100.00	35,831,239,000	100.00
	1918	22,546	100.00	31,890,494,000	100.00
Class 5: 10,000,000 feet and over per year	1914	867	3.15	20,934,446,000	56.06
	1915	846	2.82	20,669,746,000	55.84
	1916	925	3.08	23,310,137,000	58.56
	1917	899	3.62	22,148,570,000	61.81
	1918	785	3.48	18,970,552,000	59.49
Class 4: 5,000,000 to 9,999,000 feet per year	[1] 1914	547	1.99	3,910,370,000	10.47
	1915	453	1.51	3,224,448,000	8.71
	1916	484	1.61	3,513,767,000	8.82
	1917	459	1.85	3,360,502,000	9.38
	1918	505	2.24	3,567,104,000	11.19
Class 3: 1,000,000 to 4,999,000 feet per year	[1] 1914	3,291	11.97	6,078,730,000	16.28
	1915	3,191	10.65	6,201,864,000	16.76
	1916	3,041	10.11	5,858,675,000	14.72
	1917	2,352	9.48	4,615,941,000	12.88
	1918	2,194	9.73	4,270,755,000	13.39
Class 2: 500,000 to 999,000 feet per year	[1] 1914	4,261	15.49	2,780,184,000	7.44
	1915	4,198	14.02	2,941,264,000	7.95
	1916	4,594	15.27	3,096,760,000	7.78
	1917	3,689	14.87	2,460,685,000	6.87
	1918	3,183	14.12	2,138,005,000	6.70
Class 1: 50,000 to 499,000 feet per year	[1] 1914	18,540	67.40	3,642,293,000	9.75
	1915	21,263	70.99	3,974,334,000	10.74
	1916	21,037	69.93	4,027,912,000	10.12
	1917	17,416	70.18	3,245,541,000	9.06
	1918	15,879	70.43	2,944,078,000	9.23

[1] The data shown for 1914 is quantity actually reported cut.

TABLE 3.—*Reported number of days operated, yearly output, cut per 10-hour day,*[1] *and estimated daily capacity, for average mill, by States and classes: 1918.*

State.	Class 5.				Class 4.			
	Average number of 10-hour days operated.	Average yearly output per mill.	Average cut per 10-hour day per mill.	Estimated daily capacity per mill.	Average number of 10-hour days operated.	Average yearly output per mill.	Average cut per 10-hour day per mill.	Estimated daily capacity per mill.
		Feet b. m.	*Feet b. m.*	*Feet b. m.*		*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
Alabama	245	22,302,444	91,030	97,778	214	6,252,800	29,219	41,600
Arizona	(2)	19,163,000	(2)	(3)	...	...	...	...
Arkansas	250	21,886,500	87,621	104,107	214	6,771,143	27,734	33,571
California and Nevada	(2)	27,694,050	(2)	137,563	(2)	6,321,700	(2)	61,750
Colorado	...	...	...	(2)	...	...	...	...
Connecticut	...	...	...	...	...	...	...	...
Delaware	...	...	...	...	...	...	...	...
Florida	328	22,582,273	68,810	83,182	207	7,034,200	34,015	48,000
Georgia	257	16,324,000	63,518	90,000	234	5,443,000	23,261	32,500
Idaho	(2)	27,670,000	(2)	147,500	(2)	6,065,000	(2)	56,250
Illinois	...	...	...	...	...	...	...	...
Indiana	...	...	...	...	290	5,163,000	17,803	30,000
Iowa	...	...	...	...	...	...	...	...
Kansas and Nebraska	...	...	...	...	...	...	...	...
Kentucky	288	22,373,000	77,684	80,000	277	6,531,000	23,578	35,000
Louisiana	282	25,445,097	90,166	101,226	207	7,272,167	35,160	45,000
Maine	192	15,791,000	82,245	141,000	260	6,982,000	26,854	33,520
Maryland	...	...	...	...	110	8,166,000	74,236	80,000
Massachusetts	...	...	...	...	...	...	...	...
Michigan	285	15,973,182	56,082	73,182	221	7,013,000	31,709	38,583
Minnesota	212	21,651,889	154,705	157,222	300	7,530,000	25,000	37,500
Mississippi	294	23,383,200	79,427	101,700	204	8,011,667	39,337	46,667
Missouri	227	12,212,667	53,800	51,667	180	7,000,000	38,890	40,000
Montana	(2)	31,109,000	(2)	85,000	(2)	9,752,000	(2)	75,000
New Hampshire	254	17,200,000	67,716	100,000	...	...	...	...
New Jersey	...	...	...	...	...	...	...	...
New Mexico	(2)	15,163,000	(2)	(3)	(2)	6,304,000	(2)	(3)
New York	...	...	...	...	189	5,641,000	29,926	47,500
North Carolina	330	25,013,667	75,799	78,333	220	7,770,889	35,322	55,556
Ohio	...	...	...	...	...	...	...	...
Oklahoma	294	24,099,000	81,969	82,500	...	...	...	...
Oregon	248	31,631,368	127,547	148,000	156	7,037,250	41,111	57,500
Pennsylvania	322	23,787,000	73,827	80,000	224	6,811,667	30,591	46,000
Rhode Island	...	...	...	...	...	...	...	...
South Carolina	320	23,403,500	73,079	136,250	253	8,038,500	31,836	32,500
South Dakota	(2)	18,208,000	(2)	75,000	...	...	...	...
Tennessee	270	14,169,000	52,575	77,500	208	8,001,500	38,423	52,500
Texas	299	20,559,428	68,719	84,858	209	7,772,800	37,261	58,000
Utah	...	...	...	...	...	...	...	...
Vermont	...	...	...	...	264	6,496,000	24,606	30,000
Virginia	213	11,414,500	31,048	45,750	234	7,265,250	31,048	45,750
Washington	243	28,352,347	116,676	154,000	169	7,847,429	46,434	58,813
West Virginia	269	19,213,222	71,425	83,889	230	6,948,333	30,210	44,333
Wisconsin	317	21,253,875	67,047	75,900	238	7,575,500	31,830	39,786
Wyoming	...	...	...	...	...	...	...	...

[1] Shifts reduced to 10-hour basis. [2] Data not obtained. [3] Data not given.

TABLE 3.—*Reported number of days operated, yearly output, cut per 10-hour day*[1], *and estimated daily capacity, for average mill, by States and classes: 1918*—Continued.

State.	Class 3.				Class 2.			
	Average number of 10-hour days operated.	Average yearly output per mill.	Average cut per 10-hour day per mill.	Estimated daily capacity per mill.	Average number of 10-hour days operated.	Average yearly output per mill.	Average cut per 10-hour day per mill.	Estimated daily capacity per mill.
		Feet b. m.	*Feet b. m.*	*Feet b. m.*		*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
Alabama	206	1,960,000	9,515	15,852	147	657,913	4,476	10,783
Arizona	(2)	2,349,000	(2)	(3)	(2)	688,500	(2)	(2)
Arkansas	158	2,227,346	14,109	21,712	112	704,667	6,269	10,400
California and Nevada	(2)	(3)	(2)	36,250	(2)	(3)	(2)	19,830
Colorado	(2)	1,851,000	(2)	26,250	(2)	723,500	(2)	16,250
Connecticut	168	1,100,800	6,552	10,900	179	737,667	4,121	10,167
Delaware								
Florida	214	2,235,889	10,454	17,389	216	689,000	3,190	6,438
Georgia	207	1,969,105	9,513	17,053	157	650,952	4,146	7,810
Idaho	(2)	1,435,000	(2)	37,500	(2)	663,000	(2)	30,000
Illinois					143	777,000	5,421	15,000
Indiana	224	1,533,611	6,842	9,389	162	672,823	4,147	7,500
Iowa	300	4,500,000	15,000	30,000				
Kansas and Nebraska	300	7,000,000	23,333	30,000	100	500,000	5,000	5,000
Kentucky	218	2,133,800	9,788	17,400	124	656,636	5,295	7,636
Louisiana	168	2,199,556	13,116	23,333	144	750,625	5,231	12,625
Maine	152	1,740,394	11,450	18,545	101	686,696	6,799	12,000
Maryland					190	781,400	4,113	6,000
Massachusetts	209	1,816,000	8,699	14,538	137	662,825	4,825	10,077
Michigan	175	2,145,444	12,236	20,778	66	695,500	10,538	16,000
Minnesota	158	1,004,500	6,358	12,000	85	688,333	8,066	11,667
Mississippi	174	2,006,200	11,501	19,640	111	669,567	6,008	16,433
Missouri	188	1,796,100	9,554	16,200	148	661,429	4,469	11,000
Montana	(2)	2,168,000	(2)	43,750	(2)	597,000	(2)	23,750
New Hampshire	184	1,819,771	9,870	15,771	87	658,222	7,753	10,333
New Jersey					267	570,000	2,138	3,667
New Mexico	(2)	1,365,333	(2)	(3)	(2)	529,000	(2)	(3)
New York	190	1,268,461	6,684	10,538	126	661,521	5,253	10,347
North Carolina	196	1,553,930	7,928	13,640	142	647,746	4,562	8,296
Ohio	214	1,844,300	8,618	14,300	188	702,077	3,734	7,038
Oklahoma					93	790,000	8,495	10,000
Oregon	112	2,384,208	21,288	51,250	71	663,042	9,339	20,750
Pennsylvania	228	1,438,600	6,310	16,600	181	651,717	3,608	7,560
Rhode Island	150	1,400,000	9,333	14,000	106	612,333	5,777	11,667
South Carolina	216	1,718,071	7,949	14,214	179	693,950	3,880	8,800
South Dakota	(2)	1,506,333	(2)	20,000	(2)	638,000	(2)	11,250
Tennessee	154	2,004,619	13,029	19,238	118	667,956	5,658	8,695
Texas	161	2,027,571	12,564	20,809	112	679,181	6,044	13,090
Utah	(2)	1,006,000	(2)	(3)				
Vermont	182	1,796,667	9,865	20,222	108	663,928	6,139	13,857
Virginia	169	1,861,842	11,017	17,526	135	664,651	4,923	8,357
Washington	134	2,630,250	19,629	30,563	91	698,087	7,671	23,375
West Virginia	158	2,383,000	15,082	24,300	115	664,467	5,778	9,933
Wisconsin	115	2,281,688	19,841	32,438	66	682,600	10,342	14,800
Wyoming					(2)	641,000	(2)	18,750

[1] Shifts reduced to 10-hour basis. [2] Data not obtained. [3] Data not given.

TABLE 3.—*Reported number of days operated, yearly output, cut per 10-hour day*[1], *and estimated daily capacity, for average mill, by States and classes: 1918*—Continued.

State.	Class 1.			
	Average number of 10-hour days operated.	Average yearly output per mill.	Average cut per 10-hour day per mill.	Estimated daily capacity per mill.
		Feet b. m.	*Feet b. m.*	*Feet b. m.*
Alabama	57	202,415	3,551	6,392
Arizona	(2)	177,750	(2)	(3)
Arkansas	58	171,527	2,956	7,864
California and Nevada	(2)	(3)	(2)	9,769
Colorado	(2)	163,902	(2)	10,000
Connecticut	49	133,333	2,721	5,633
Delaware	97	242,857	2,549	5,286
Florida	95	223,250	2,341	5,938
Georgia	50	151,793	3,036	5,989
Idaho	(2)	210,000	(2)	15,000
Illinois	63	177,862	2,806	5,379
Indiana	78	217,744	2,807	5,315
Iowa	39	130,958	3,336	6,313
Kansas and Nebraska	125	142,000	1,136	3,750
Kentucky	53	189,697	3,579	5,702
Louisiana	79	244,941	3,103	9,529
Maine	54	229,302	4,246	9,913
Maryland	65	207,829	3,205	5,768
Massachusetts	76	246,133	3,252	7,667
Michigan	47	210,128	4,378	10,282
Minnesota	32	170,621	5,341	9,293
Mississippi	57	223,000	3,943	7,750
Missouri	55	164,551	2,992	5,411
Montana	(2)	172,000	(2)	11,250
New Hampshire	61	254,428	4,191	10,178
New Jersey	128	159,693	1,252	3,423
New Mexico	(2)	190,455	(2)	(3)
New York	58	159,412	2,727	7,451
North Carolina	58	218,774	3,772	6,509
Ohio	74	219,852	2,971	5,483
Oklahoma	50	152,750	3,055	6,583
Oregon	37	229,456	6,202	14,838
Pennsylvania	74	195,391	2,613	6,108
Rhode Island	23	157,500	6,848	10,000
South Carolina	55	170,745	5,096	5,727
South Dakota	(2)	183,294	(2)	10,000
Tennessee	57	184,993	3,256	6,277
Texas	62	221,740	3,587	9,148
Utah	(2)	118,652	(2)	(3)
Vermont	73	217,706	2,958	9,034
Virginia	57	183,972	3,228	5,602
Washington	60	235,878	3,931	12,163
West Virginia	58	170,373	2,937	5,993
Wisconsin	30	186,722	6,224	10,167
Wyoming	(2)	134,555	(2)	7,500

[1] Shifts reduced to 10-hour basis. [2] Data not obtained. [3] Data not given.

The relative importance of each State in the aggregate cut of lumber is indicated in Table 4, which shows the cut by classes of mills arranged by States. Of the 777 class 5 mills reporting their output for 1918, 105 were located in Louisiana, 54 in Mississippi, 47 in Texas, 38 in Arkansas, and 29 in Alabama. From this group of States 273 class 5 mills reported in 1918, or a decrease of 18 per cent in comparison with the 332 mills reported in 1917. In the Lake States group were 40 in Wisconsin, 30 in Michigan, and 20 in Minnesota, a decrease of 18 per cent in number from 1917. In the western States 132 were in Washington, 72 in Oregon, and 40 in California and Nevada; the class 5 mills in these States in 1917 numbered but 221, so that there is an increase of 10 per cent.

In the 12 States mentioned above, the 607 class 5 mills reporting form 78 per cent of the total reporting from all States. From the four general producing regions embraced within these States comes the bulk of the soft wood cut.

Of the 11,437 mills reporting a cut of from 50,000 to 1,000,000 feet each, 1,089 were in Virginia, 979 in North Carolina, 977 in New York, 677 in Pennsylvania, and 632 in Tennessee. The 4,354 class 1 and class 2 mills in the five States constitute 38 per cent of the two classes of mills reporting for the entire country.

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TABLE 4.—*Sawmills classified by States, according to reported quantity of lumber cut, 1918.*

State.	Aggregate.		Class 5—Mills cutting over 10,000,000 feet.		Class 4—Mills cutting from 5,000,000 to 9,999,000 feet.		Class 3—Mills cutting from 1,000,000 to 4,999,000 feet.		Class 2—Mills cutting from 500,000 to 999,000 feet.		Class 1—Mills cutting from 50,000 to 499,000 feet.	
	Number of active mills reporting.	Quantity.	Number of mills.	Quantity.	Number of mills.	Quantity.	Number of mills.	Quantity.	Number of mills.	Quantity.	Number of mills.	Quantity.
		Feet b. m.		*Feet b. m.*		*Feet b. m.*		*Feet b. m.*		*Feet b. m.*		*Feet b. m.*
United States	14,753	29,362,020,000	777	18,780,191,000	485	3,425,833,000	2,054	3,998,243,000	2,133	1,432,726,000	9,304	1,725,027,000
Alabama	678	1,134,393,000	29	546,713,000	24	176,080,000	130	269,410,000	100	67,855,000	395	74,335,000
Arizona	19	82,511,000	4	76,652,000			1		2	[1] 3,726,000	12	2,133,000
Arkansas	612	1,327,393,000	38	757,524,000	29	211,550,000	107	241,307,000	82	55,735,000	356	61,277,000
California and Nevada	153	1,277,084,000	40	1,107,762,000	10	63,217,000	33	81,742,000	21	14,281,000	49	10,082,000
Colorado	114	54,632,000					16	29,616,000	16	11,576,000	82	13,440,000
Connecticut	128	57,022,000					13	17,738,000	36	25,712,000	79	13,572,000
Delaware	25	5,200,000							2		23	[2] 5,200,000
Florida	191	862,580,000	30	564,541,000	21	150,686,000	56	119,022,000	24	16,746,000	60	11,585,000
Georgia	481	463,472,000	11	159,782,000	10	73,101,000	79	131,739,000	76	50,160,000	305	48,690,000
Idaho	173	802,529,000	22	698,605,000	6	43,604,000	21	31,092,000	18	12,154,000	106	17,074,000
Illinois	94	36,459,000			2		3	[3] 15,849,000	9	6,160,000	80	14,450,000
Indiana	358	185,619,000			2		53	[3] 105,673,000	44	28,804,000	359	51,142,000
Iowa	57	13,025,000					1		3	[1] 6,305,000	53	6,720,000
Kansas and Nebraska	9	8,280,000			1				1		7	[4] 8,280,000
Kentucky	464	246,656,000	3	45,972,000	7	49,133,000	19	49,823,000	51	34,114,000	384	67,614,000
Louisiana	310	3,158,736,000	105	2,666,341,000	35	263,485,000	77	194,840,000	27	19,359,000	66	14,711,000
Maine	476	570,846,000	5	85,461,000	20	133,745,000	123	237,187,000	92	62,801,000	236	51,652,000
Maryland	199	66,378,000			1		6	[5] 19,841,000	21	14,610,000	171	31,927,000
Massachusetts	227	151,217,000			2		53	[3] 95,099,000	41	29,105,000	131	27,013,000
Michigan	271	801,967,000	30	463,925,000	33	231,384,000	30	63,782,000	20	13,749,000	158	29,127,000
Minnesota	203	911,453,000	20	785,732,000	8	62,193,000	17	24,135,000	21	13,932,000	137	25,461,000
Mississippi	601	1,786,082,000	54	1,152,662,000	38	268,235,000	125	234,074,000	108	72,331,000	276	58,780,000
Missouri	343	241,039,000	6	77,760,000	7	49,436,000	29	51,015,000	30	18,913,000	271	43,915,000
Montana	98	335,811,000	8	271,912,000	2		12	[3] 47,010,000	8	5,065,000	68	11,824,000
New Hampshire	271	304,999,000	1		1		120	[6] 244,996,000	53	37,575,000	96	22,428,000

New Jersey	70	15,755,000							5	3,460,000	65	12,295,000
New Mexico	47	85,215,000	3	45,489,000	2		15	[3] 32,891,000	5	2,645,000	22	4,190,000
New York	1,023	328,841,000	1		5	[7] 45,696,000	40	71,215,000	107	68,615,000	870	143,315,000
North Carolina	1,192	1,066,839,000	16	243,563,000	34	239,658,000	163	287,103,000	218	142,567,000	761	153,948,000
Ohio	449	190,920,000			3	18,871,000	33	50,106,000	74	51,021,000	339	70,922,000
Oklahoma	83	172,294,000	5	130,946,000			14	26,735,000	8	5,551,000	56	9,062,000
Oregon	476	2,708,955,000	72	2,258,007,000	23	143,733,000	94	209,347,000	90	57,911,000	197	39,957,000
Pennsylvania	719	445,313,000	8	187,629,000	4	26,733,000	30	43,360,000	117	77,561,000	560	110,030,000
Rhode Island	16	12,250,000					5	7,698,000	4	2,437,000	7	2,115,000
South Carolina	352	483,009,000	10	174,586,000	17	113,869,000	67	118,661,000	64	45,210,000	194	30,683,000
South Dakota	26	29,033,000	1				3	[7] 22,727,000	5	3,190,000	17	3,116,000
Tennessee	725	492,225,000	7	103,208,000	20	124,294,000	66	117,564,000	70	45,315,000	562	101,844,000
Texas	244	1,215,192,000	47	981,254,000	12	89,310,000	50	98,784,000	38	24,557,000	97	21,287,000
Utah	67	8,837,000					1				66	[1] 8,837,000
Vermont	266	123,558,000			1		27	[5] 50,316,000	49	33,826,000	189	39,416,000
Virginia	1,222	769,544,000	13	196,391,000	14	98,883,000	106	172,734,000	220	147,103,000	869	154,433,000
Washington	455	4,602,469,000	132	3,929,107,000	43	327,818,000	128	287,925,000	54	35,787,000	98	21,832,000
West Virginia	370	598,194,000	16	260,376,000	25	161,878,000	40	94,910,000	56	40,589,000	233	40,441,000
Wisconsin	358	1,122,068,000	40	762,464,000	23	178,357,000	48	113,033,000	41	28,680,000	206	39,534,000
Wyoming	38	6,126,000							2		36	[2] 6,126,000

[1] Includes the cut of 1 mill in class 3.
[2] Includes the cut of 2 mills in class 2.
[3] Includes the cut of 2 mills in class 4.
[4] Includes the cut of 1 mill in class 4 and 1 mill in class 2.
[5] Includes the cut of 1 mill in class 4.
[6] Includes the cut of 1 mill in class 5 and 1 mill in class 4.
[7] Includes the cut of 1 mill in class 5.

LUMBER PRODUCTION BY STATES.

The total number of sawmills in operation and the total quantity of lumber reported cut in each State for the last 10 years—1909 to 1918, inclusive—are shown in Table 5. The figures accurately portray the fluctuations in the lumber trade for the period covered. Only three of the leading producing States show a gain in output in 1918 over the year before, and these States are in the western group. The increase in Washington, which ranks first in volume of production amounted to less than 1 per cent; in Oregon the increase was 5 per cent, and in Idaho 6 per cent. Production in all of the southern pine States markedly declined from the year before. In comparison with the 1917 output the cut was 18 per cent smaller in Louisiana, 20 per cent in Mississippi, 17 per cent in Arkansas, 22 per cent in Texas, 18 per cent in Alabama, 23 per cent in Florida, and 30 per cent in Georgia. A largely decreased output also is in evidence for the North Carolina pine group of States; in North Carolina the decline amounted to 15 per cent, in Virginia to 19 per cent, and in South Carolina to 27 per cent. The cut in the Lake States was likewise less than for the year before. In Wisconsin the production was less by 8 per cent, in Minnesota 7 per cent, and in Michigan 12 per cent. Other changes in production among the minor producing States may be attributed to more or less local conditions.

TABLE 5.—*Total number of active sawmills reporting and quantity of lumber reported or computed, by States, 1909–1918.*

State.	Computed totals.				Reported totals.					
	1918 (22,546 mills).	1917 (24,815 mills).	1916 (30,081 mills).	1915 (29,951 mills).	1914[1] (27,506 mills).	1913 (21,668 mills).	1912 (29,005 mills).	1911[2] (28,107 mills).	1910[2] (31,934 mills).	1909 (46,584 mills).
	Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
Total	[3]31,890,494,000	[3]35,831,239,000	[3]39,807,251,000	[3]37,011,656,000	[3]37,346,023,000	[3]38,387,009,000	[3]39,158,414,000	[3]37,003,207,000	[3]40,018,282,000	44,509,761,000
Washington	4,603,123,000	4,568,500,000	4,494,000,000	3,950,000,000	3,946,189,000	4,592,053,000	4,099,775,000	4,064,754,000	4,097,492,000	3,862,916,000
Louisiana	3,450,000,000	4,210,000,000	4,200,000,000	3,900,000,000	3,956,434,000	4,161,560,000	3,876,211,000	3,566,456,000	3,733,900,000	3,551,918,000
Oregon	2,710,250,000	2,585,000,000	2,222,000,000	1,690,000,000	1,817,875,000	2,098,467,000	1,916,160,000	1,803,698,000	2,084,633,000	1,898,995,000
Mississippi	1,935,000,000	2,425,000,000	2,730,000,000	2,300,000,000	2,280,966,000	2,610,581,000	2,381,898,000	2,041,615,000	2,122,205,000	2,572,669,000
Arkansas	1,470,000,000	1,765,000,000	1,910,000,000	1,800,000,000	1,796,780,000	1,911,647,000	1,821,811,000	1,777,303,000	1,844,446,000	2,111,300,000
Texas	1,350,000,000	1,735,000,000	2,100,000,000	1,750,000,000	1,554,005,000	2,081,471,000	1,902,201,000	1,681,080,000	1,884,134,000	2,099,130,000
California	[4]1,277,084,000	[4]1,417,068,000	[4]1,420,000,000	[4]1,130,000,000	1,303,183,000	1,183,380,000	1,203,059,000	1,207,561,000	1,254,826,000	1,143,507,000
Wisconsin	1,275,000,000	1,385,000,000	1,600,000,000	1,210,000,000	1,391,001,000	1,493,353,000	1,498,876,000	1,761,986,000	1,891,291,000	2,025,038,000
Alabama	1,270,000,000	1,555,000,000	1,720,000,000	1,500,000,000	1,494,732,000	1,523,936,000	1,378,151,000	1,226,212,000	1,465,623,000	1,691,001,000
North Carolina	1,240,000,000	1,460,000,000	2,100,000,000	2,090,000,000	2,227,854,000	1,957,258,000	2,193,308,000	1,798,724,000	1,824,722,000	2,177,715,000
Minnesota	1,005,000,000	1,075,000,000	1,220,000,000	1,100,000,000	1,312,230,000	1,149,704,000	1,436,726,000	1,485,015,000	1,457,734,000	1,561,508,000
Florida	950,000,000	1,230,000,000	1,425,000,000	1,110,000,000	1,073,821,000	1,055,047,000	1,067,525,000	983,824,000	992,091,000	1,201,734,000
Michigan	940,000,000	1,065,000,000	1,230,000,000	1,100,000,000	1,214,435,000	1,222,983,000	1,488,827,000	1,466,754,000	1,681,081,000	1,889,724,000
Virginia	855,000,000	1,060,000,000	1,335,000,000	1,500,000,000	1,488,070,000	1,273,953,000	1,569,997,000	1,359,790,000	1,652,192,000	2,101,716,000
Idaho	802,529,000	760,000,000	849,600,000	777,000,000	763,508,000	652,616,000	713,575,000	765,670,000	745,984,000	645,800,000
West Virginia	720,000,000	890,000,000	1,220,000,000	1,100,000,000	1,118,480,000	1,249,559,000	1,318,732,000	1,387,786,000	1,376,737,000	1,472,942,000
Maine	650,000,000	770,000,000	935,000,000	1,000,000,000	992,594,000	834,673,000	882,128,000	828,417,000	860,273,000	1,111,565,000
Tennessee	630,000,000	630,000,000	700,000,000	800,000,000	885,035,000	872,311,000	932,572,000	914,579,000	1,016,475,000	1,223,849,000
South Carolina	545,000,000	745,000,000	857,000,000	800,000,000	701,540,000	752,184,000	816,930,000	584,872,000	706,831,000	897,660,000
Pennsylvania	530,000,000	565,000,000	750,000,000	950,000,000	864,710,000	781,547,000	992,180,000	1,048,606,000	1,241,199,000	1,462,771,000
Georgia	515,000,000	740,000,000	1,000,000,000	1,000,000,000	1,026,191,000	844,284,000	941,291,000	801,611,000	1,041,617,000	1,342,249,000
New Hampshire	350,000,000	290,000,000	385,000,000	500,000,000	482,744,000	309,424,000	479,499,000	388,619,000	443,907,000	649,606,000
Kentucky	340,000,000	360,000,000	525,000,000	560,000,000	596,392,000	541,531,000	641,296,000	632,415,000	753,556,000	860,712,000
Montana	340,000,000	350,000,000	383,900,000	328,000,000	317,842,000	357,974,000	272,174,000	228,416,000	319,089,000	308,582,000
New York	335,000,000	360,000,000	400,000,000	475,000,000	486,195,000	457,720,000	502,351,000	526,283,000	506,074,000	681,440,000
Missouri	273,000,000	275,000,000	260,000,000	350,000,000	370,571,000	416,608,000	422,470,000	418,586,000	501,691,000	660,159,000
Indiana	250,000,000	240,000,000	270,000,000	350,000,000	298,571,000	332,993,000	401,017,000	360,613,000	422,963,000	556,418,000
Ohio	235,000,000	225,000,000	280,000,000	400,000,000	286,063,000	414,943,000	499,834,000	427,161,000	490,039,000	542,904,000
Oklahoma	195,000,000	240,000,000	240,000,000	230,000,000	200,594,000	140,284,000	168,806,000	143,869,000	164,663,000	225,730,000
Massachusetts	175,000,000	155,000,000	210,000,000	250,000,000	143,094,000	224,580,000	259,329,000	273,317,000	239,206,000	361,200,000

[1] Custom mills excluded.
[2] Includes also exclusive lath and shingle mills reporting (1,500 estimated).
[3] Mills cutting less than 50,000 feet per year excluded.
[4] Includes cut of mills in Nevada.

TABLE 5.—*Total number of active sawmills reporting and quantity of lumber reported or computed, by States, 1909–1918*—Continued.

State.	Computed totals.				Reported totals.					
	1918 (22,546 mills).	1917 (24,815 mills).	1916 (30,081 mills).	1915 (29,951 mills).	1914 (27,506 mills).	1913 (21,668 mills).	1912 (29,005 mills).	1911 (28,107 mills).	1910 (31,934 mills).	1909 (46,584 mills).
	Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
Vermont	160,000,000	170,000,000	200,000,000	260,000,000	249,608,000	194,647,000	235,983,000	239,254,000	284,815,000	351,571,000
New Mexico	88,915,000	93,000,000	91,600,000	65,787,000	57,167,000	65,818,000	82,650,000	83,728,000	83,544,000	91,987,000
Arizona	83,661,000	79,022,000	93,270,000	75,915,000	78,667,000	77,363,000	76,287,000	73,139,000	72,655,000	62,731,000
Maryland	71,000,000	68,000,000	90,237,000	165,000,000	162,097,000	140,469,000	174,320,000	144,078,000	154,554,000	267,939,000
Connecticut	64,000,000	66,000,000	75,000,000	90,000,000	81,883,000	93,730,000	109,251,000	124,661,000	126,463,000	168,371,000
Colorado	56,882,000	71,500,000	77,580,000	74,500,000	102,117,000	74,602,000	88,451,000	95,908,000	121,398,000	141,710,000
Illinois	42,000,000	45,000,000	60,000,000	110,000,000	66,227,000	102,902,000	122,528,000	96,651,000	113,506,000	170,181,000
South Dakota	29,533,000	29,045,000	29,650,000	22,562,000	18,744,000	19,103,000	20,986,000	13,046,000	16,340,000	31,057,000
New Jersey	19,500,000	25,000,000	40,000,000	45,000,000	48,748,000	27,248,000	34,810,000	28,639,000	36,542,000	61,620,000
Iowa	14,200,000	13,436,000	20,000,000	35,000,000	11,443,000	21,676,000	46,593,000	59,974,000	75,446,000	132,021,000
Rhode Island	13,100,000	10,646,000	18,000,000	15,000,000	15,902,000	14,984,000	14,421,000	9,016,000	14,392,000	25,489,000
Utah	9,815,000	8,567,000	9,385,000	10,892,000	8,680,000	5,403,000	9,055,000	10,573,000	11,786,000	12,638,000
Kansas	[1] 8,401,000	4,255,000	534,000	....	....	....	....	....	....	....
Wyoming	7,501,000	8,700,000	18,495,000	17,000,000	11,852,000	12,940,000	13,560,000	33,309,000	30,931,000	28,602,000
Delaware	6,000,000	8,500,000	12,000,000	25,000,000	25,517,000	18,039,000	28,285,000	23,853,000	46,642,000	55,440,000
All other States	....	....	....	....	[2] 15,672,000	[2] 19,461,000	[2] 22,525,000	[2] 11,786,000	[2] 12,594,000	[2] 15,946,000

[1] Includes cut of mills in Nebraska.

[2] Includes Kansas, Nebraska, and Nevada.

The relative importance of the several general producing regions of the country at 10-year periods since the middle of the last century is shown in Table 6. The history of the lumber industry is traceable in the tabulation, since it shows the inception of lumbering in each region and its growth or decline during subsequent intervals.

TABLE 6.—*Lumber cut by groups of States, in per cent of the total.*

Groups.	1850	1860	1870	1880	1890	1899	1909	1918
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Northeastern group	54.8	37.0	37.8	25.8	19.8	16.3	11.7	7.4
Central group	18.6	21.1	20.0	18.4	13.1	16.1	12.3	7.8
Southern group	8.5	13.0	6.9	9.7	15.6	24.0	33.3	34.9
North Carolina pine group	5.1	4.8	2.5	4.1	4.7	7.7	11.6	8.3
Lake States group	6.3	13.6	24.4	34.7	34.6	24.9	12.3	10.1
Pacific group	5.9	6.4	4.0	3.6	8.5	8.3	15.5	26.9
Rocky Mountain group	.0	.1	.9	.9	1.1	1.6	2.9	4.4
All other	.8	4.0	3.5	2.8	2.6	1.1	.4	.2

Northeastern group.—Connecticut, Delaware, Maryland, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
Central group.—Illinois, Indiana, Kentucky, Missouri, Ohio, Tennessee, West Virginia.
Southern group.—Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Oklahoma, Texas.
North Carolina pine group.—North Carolina, South Carolina, Virginia.
Lake States group.—Michigan, Minnesota, Wisconsin.
Pacific group.—California, Nevada, Oregon, Washington.
Rocky Mountain group.—Arizona, Colorado, Idaho, Montana, New Mexico, Utah, Wyoming.
All other.—Iowa, Kansas, Nebraska, South Dakota.

LUMBER PRODUCTION BY KINDS OF WOOD.

Table 7 shows for each of the last 10 years, 1909 to 1918, the computed cut of the different woods. In a preceding table the lessened cut was shown by States, while in this table the decline in output is revealed according to species. Only three woods on the entire list show a greater computed cut in 1918 than in 1917. These are Douglas fir with an increase of 4 per cent, hickory with 5 per cent, and walnut with 61 per cent. The enlarged cut of walnut was due entirely to the demand for this wood for war purposes.

The decrease in yellow pine production from 1917 amounted to more than 2,500,000,000 feet, or 20 per cent. As between 1917 and 1916 the cut of yellow pine fell off 10 per cent. The 1918 cut was more than 4,000,000,000 feet less than in 1916. Others of the more important softwoods, the cut of which declined from the year before, are white pine 2 per cent, hemlock 15 per cent, and western yellow pine 13 per cent. Cypress production decreased 34 per cent. Among the hardwoods the computed output of oak was less by 10 per cent and that of yellow poplar by 17 per cent.

Softwood production forms approximately four-fifths of the aggregate annual cut. The 1918 cut of softwoods was 12 per cent smaller than in 1917; the hardwood cut was 7 per cent smaller than in 1917.

Figures 2 and 3 supplement Tables 5 and 7 by showing graphically the computed figures on 1918 lumber production, by States and by species, respectively.

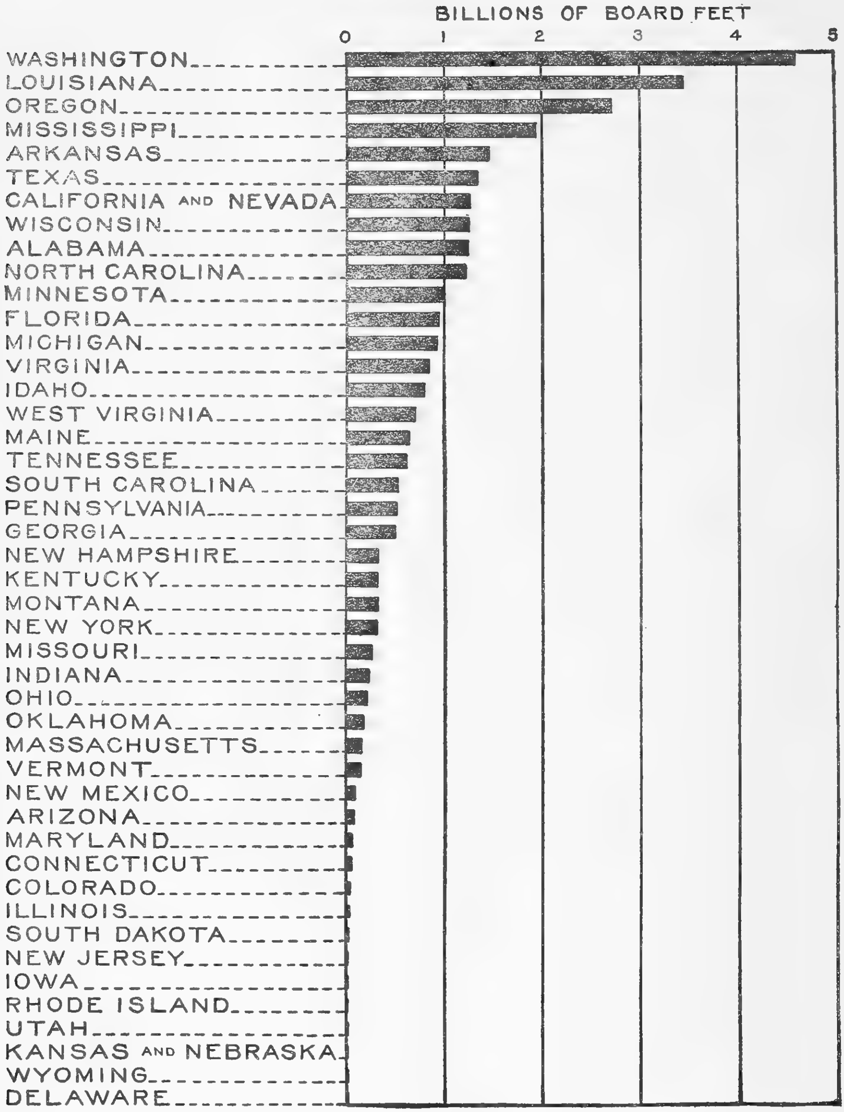

FIG. 2.—Computed lumber production in 1918, by States.

The several woods which go to make up the bulk of the lumber cut in the United States are treated individually in the following pages. The tabulation for each species shows by States the number of active mills reporting, the quantity reported cut, the proportion of the total reported cut, the average value per thousand feet f. o. b. mill, and the computed total cut. The average values given in the tables are the weighted averages of about 50 per cent of the 14,753 mills which reported their cut, and accurately reflect the true value of the several species of lumber at the mill. The variation in values for the same wood in different States is caused by character of timber, type of manufacture, and distance from market.

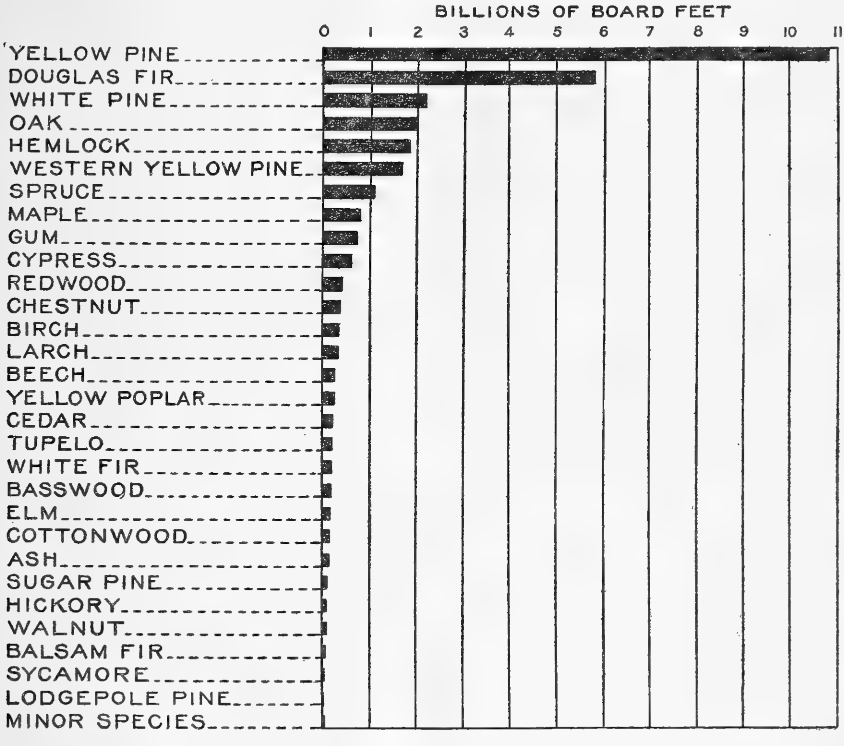

FIG. 3.—Computed total lumber production in 1918, by kinds of wood.

The question is frequently asked in connection with lumber production figures as to what part shortleaf pine forms of the total quantity of yellow pine reported, or the ratio of white oak cut to the total. It is not practicable in the lumber census work to do more than group the figures for all of the yellow pines together, and treat the oaks, gums, cedars, and other woods in the same way, since no standard classification is found among the lumbermen. Producers in one section frequently apply a local name to a given species and only confusion would follow an attempt to segregate the figures.

TABLE 7.—*Quantity of each kind of lumber reported, 1909–1914, and computed total production, 1915–1918, by kinds of wood.*

	Computed totals.				Reported totals.					
	1918	1917	1916	1915	1914	1913	1912	1911	1910	1909
	Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
Total	31,890,494,000	35,831,239,000	39,807,251,000	37,011,656,000	37,346,023,000	38,387,009,000	39,158,414,000	37,003,207,000	40,018,282,000	44,509,761,000
Yellow pine	10,845,000,000	13,539,464,000	15,055,000,000	14,700,000,000	14,472,804,000	14,839,363,000	14,737,052,000	12,896,706,000	14,143,471,000	16,277,185,000
Douglas fir	5,820,000,000	5,585,000,000	5,416,000,000	4,431,349,000	4,763,693,000	5,556,096,000	5,175,123,000	5,054,243,000	5,203,644,000	4,856,378,000
White pine	2,200,000,000	2,250,000,000	2,700,000,000	2,700,000,000	2,632,587,000	2,568,636,000	3,138,227,000	3,230,584,000	3,352,183,000	3,900,034,000
Oak	2,025,000,000	2,250,000,000	3,300,000,000	2,970,000,000	3,278,908,000	3,211,718,000	3,318,952,000	3,098,444,000	3,522,098,000	4,414,457,000
Hemlock	1,875,000,000	2,200,000,000	2,350,000,000	2,275,000,000	2,165,728,000	2,319,982,000	2,426,554,000	2,255,308,000	2,836,129,000	3,051,399,000
Western yellow pine	1,710,000,000	1,960,000,000	1,690,000,000	1,293,985,000	1,327,365,000	1,258,528,000	1,219,444,000	1,330,700,000	1,562,106,000	1,499,985,000
Spruce	1,125,000,000	1,125,000,000	1,250,000,000	1,400,000,000	1,245,614,000	1,046,816,000	1,238,600,000	1,261,728,000	1,449,912,000	1,748,547,000
Maple	815,000,000	860,000,000	975,000,000	900,000,000	909,743,000	901,487,000	1,020,864,000	951,667,000	1,006,637,000	1,106,604,000
Gum	765,000,000	788,000,000	800,000,000	655,000,000	675,380,000	772,514,000	694,260,000	582,967,000	610,208,000	706,945,000
Cypress	630,000,000	950,000,000	1,000,000,000	1,100,000,000	1,013,013,000	1,097,247,000	997,227,000	981,527,000	935,659,000	955,635,000
Redwood	443,231,000	487,458,000	490,850,000	420,294,000	535,199,000	510,271,000	496,796,000	489,768,000	543,493,000	521,630,000
Chestnut	400,000,000	415,000,000	535,000,000	490,000,000	540,591,000	505,802,000	554,230,000	529,022,000	535,049,000	663,891,000
Birch	370,000,000	415,000,000	450,000,000	415,000,000	430,667,000	378,739,000	388,272,000	432,571,000	420,769,000	452,370,000
Larch	355,000,000	360,000,000	455,000,000	375,000,000	358,561,000	395,273,000	407,064,000	368,216,000	382,514,000	421,214,000
Beech	290,000,000	296,000,000	360,000,000	360,000,000	376,464,000	365,501,000	435,250,000	403,881,000	437,325,000	511,244,000
Yellow poplar	290,000,000	350,000,000	560,000,000	464,000,000	519,221,000	620,176,000	623,289,000	659,475,000	734,926,000	858,500,000
Cedar	245,000,000	265,000,000	410,000,000	420,000,000	499,903,000	358,444,000	329,000,000	374,925,000	415,039,000	346,008,000
Tupelo	237,000,000	265,000,000	275,000,000	170,000,000	124,480,000	120,420,000	122,545,000	98,142,000	92,071,000	96,676,000
White fir	213,000,000	218,200,000	190,000,000	125,048,000	112,627,000	88,109,000	122,613,000	124,307,000	132,327,000	89,318,000
Basswood	200,000,000	203,000,000	275,000,000	260,000,000	264,656,000	257,102,000	296,717,000	304,621,000	344,704,000	399,151,000
Elm	195,000,000	205,000,000	240,000,000	210,000,000	214,294,000	214,532,000	262,141,000	236,108,000	265,107,000	347,456,000
Cottonwood	175,000,000	190,000,000	200,000,000	180,000,000	195,198,000	208,938,000	227,477,000	198,629,000	220,305,000	265,600,000
Ash	170,000,000	175,000,000	210,000,000	190,000,000	189,499,000	207,816,000	234,548,000	214,398,000	246,035,000	291,209,000
Sugar pine	111,800,000	132,600,000	169,250,000	117,701,000	136,159,000	149,926,000	132,416,000	117,987,000	103,165,000	97,191,000
Hickory	100,000,000	95,000,000	125,000,000	100,000,000	116,113,000	162,980,000	278,757,000	240,217,000	272,252,000	333,929,000
Walnut	100,000,000	62,000,000	90,000,000	90,000,000	25,573,000	40,565,000	43,083,000	38,293,000	36,449,000	46,108,000
Balsam fir	82,000,000	88,900,000	125,000,000	100,000,000	125,212,000	93,752,000	84,261,000	83,375,000	74,580,000	108,702,000
Sycamore	30,000,000	32,000,000	40,000,000	25,000,000	22,773,000	30,804,000	49,468,000	42,836,000	45,063,000	56,511,000
Lodgepole pine	12,500,000	12,500,000	30,800,000	26,486,000	18,374,000	20,106,000	22,039,000	33,014,000	26,634,000	23,733,000
All other kinds	60,963,000	56,117,000	40,351,000	47,893,000	55,624,000	85,366,000	82,145,000	69,548,000	68,428,000	62,151,000

YELLOW PINE.

The reported cut of yellow pine for 1918 was 20 per cent under that for 1917 and is the smallest cut recorded since 1899, with the exception of 1905. Since yellow pine production formed 34 per cent of the country's aggregate lumber output, the economic importance of the decline becomes the more marked. Embraced in the classification of yellow pine is the longleaf pine cut in the Southern and Gulf States, the shortleaf pine from the same region as well as Arkansas, and the shortleaf and loblolly pine of the North Carolina pine region.

The lessened output was general among the larger producing States. In Missouri and Maryland alone the 1918 cut was in excess of that reported in 1917. The decrease ranged from 17 per cent in both Louisiana and North Carolina to as high as 36 per cent in Georgia. Through the greater loss in output in Arkansas, that State displaced North Carolina in seventh place in the rank of producing States.

Reports were received from 5,289 active mills in 1918, whereas 6,217 mills reported in 1917.

The average value of yellow pine f. o. b. mill for the year was $24.38. The figure represents an increase of $5.38 per 1,000 feet; or 28 per cent, over the year before. The average value rose 33 per cent in 1917 over 1916.

TABLE 8.—*Reported production of yellow pine*[1] *lumber in 1918.*

[Computed total production in the United States, 10,845,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	5,289	9,941,997,000	100.0	$24.38
Louisiana	225	2,486,847,000	25.0	25.13
Mississippi	488	1,448,893,000	14.6	24.52
Texas	230	1,172,154,000	11.8	25.27
Alabama	638	1,037,659,000	10.4	22.27
North Carolina	1,008	782,027,000	7.9	23.09
Florida	184	765,912,000	7.7	24.21
Arkansas	260	742,236,000	7.5	25.15
Virginia	820	454,015,000	4.6	24.81
South Carolina	349	416,536,000	4.2	25.62
Georgia	465	352,682,000	3.5	22.08
Oklahoma	51	147,494,000	1.5	20.79
Missouri	84	42,062,000	.4	23.20
Tennessee	211	37,474,000	.4	18.83
Maryland	118	30,223,000	.3	23.65
All other States (see Summary, p. 42)	158	25,783,000	.2	25.13

[1] Longleaf pine (*Pinus palustris*), also known as Georgia pine and hard pine and exported as pitch pine; cut mostly in the Gulf States.
North Carolina pine (*Pinus tæda*), also called shortleaf, loblolly, old field, rosemary, and Virginia pine; cut mostly in Virginia, North and South Carolina, Arkansas, and Texas.
Shortleaf pine (*Pinus echinata*); cut mostly in Virginia, North and South Carolina, Arkansas, Louisiana, and Mississippi.
Sand pine (*Pinus clausa*); Florida and Alabama.
Slash (or Cuban) pine (*Pinus caribæa*); cut mostly in Georgia and the Gulf States east of the Mississippi River.
Scrub pine (*Pinus virginiana*), also called Jersey pine; cut in the Middle Atlantic States.
Pitch pine (*Pinus rigida*); Middle Atlantic and Northern States.
Spruce pine (*Pinus glabra*); Gulf States.
Pond pine (*Pinus serotina*); South Atlantic States.
Table-mountain pine (*Pinus pungens*); Appalachian Mountains.

DOUGLAS FIR.

The reported production of Douglas fir, amounting to 5,819,141,000 feet, exceeded the 1917 output by 9 per cent. The computed total cut of 5,820,000,000 feet is the largest for any year for which figures are available. In 1917 the cut of Douglas fir formed 16 per cent of the aggregate output of all lumber in the United States; in 1918, the cut was 20 per cent, or one-fifth, of the total. The 1,101 mills reporting are an increase of 77 mills over the year before. In Washington and Oregon production was slightly larger in 1918, and in California production increased 40 per cent over 1917 with a smaller number of mills reporting. In Idaho and Montana the output decreased.

The average value per thousand feet increased from $16.28 in 1917 to $18.77, or 15 per cent. The 1918 figure is the topmost price recorded for this wood.

TABLE 9.—*Reported production of Douglas fir*[1] *lumber, 1918.*

[Computed total production in the United States, 5,820,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	1,101	5,819,141,000	100.0	$18.77
Washington	363	3,578,831,000	61.5	19.54
Oregon	407	1,898,080,000	32.6	17.09
California	78	219,267,000	3.8	20.32
Idaho	116	72,658,000	1.2	19.45
Montana	56	34,906,000	.6	19.38
All other States (see Summary p. 42)	81	15,399,000	.3	23.13

[1] Douglas fir (*Pseudotsuga taxifolia*) is the principal commercial species.

WHITE PINE.

White pine production reported in 1918 was smaller by 4 per cent than in 1917, the total cut amounting to 1,968,474,000 feet. In spite of the fact that it is the smallest quantity cut in more than a decade, white pine assumes the position occupied by oak in recent years in point of production. The 1918 white pine cut was 8 per cent below the 1917 cut in Minnesota, 7 per cent in Maine, and 21 per cent in Wisconsin; the cut gained by 8 per cent in Idaho and 10 per cent in New Hampshire.

The average value of white pine rose from $24.81 per 1,000 feet in 1917 to $30.84 in 1918, an increase of 24 per cent.

TABLE 10.—*Reported production of white pine*[1] *lumber, 1918.*

[Computed total production in the United States, 2,200,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	2,638	1,968,474,000	100.0	$30.84
Minnesota	154	830,439,000	42.2	30.77
Maine	376	237,466,000	12.1	28.21
Idaho	34	208,749,000	10.6	32.84
New Hampshire	247	188,569,000	9.6	28.78
Wisconsin	194	126,228,000	6.4	35.48
Massachusetts	194	99,377,000	5.0	26.72
Washington	31	65,856,000	3.3	25.45
New York	594	59,842,000	3.0	32.51
Michigan	124	46,664,000	2.4	35,47
Vermont	101	25,722,000	1.3	29.41
Pennsylvania	240	24,615,000	1.3	35.34
Virginia	89	9,410,000	.5	25.70
Connecticut	50	8,597,000	.4	34.09
Tennessee	39	8,017,000	.4	29.55
North Carolina	44	7,437,000	.4	27.71
All other States (see Summary p. 42)	127	21,486,000	1.1	27.28

[1] White pine (*Pinus strobus*) is the white pine cut in the Lake States, the Northeastern States, and the Appalachian region.
Norway (or red) pine (*Pinus resinosa*), though botanically a yellow pine, is cut in the Lake States and largely marketed with white pine.
Jack pine (*Pinus banksiana*) is cut in the Lake States.
Western white pine (*Pinus monticola*) is cut in Idaho, Montana, Washington, and Oregon.

OAK.

The production of oak in the United States has decreased annually during the last 10 years and more, as a result of the depletion of oak timber and the wider use of a greater variety of hardwoods. In 1918 the reported cut was 1,658,714,000 feet, in comparison with 1,967,694,000 feet in 1917, a decrease of 16 per cent. The 1917 cut was 9 per cent less than that of 1916. The shifting center of oak production is indicated by Arkansas taking the place of West Virginia as the principal producing State. Arkansas, Louisiana, and New York were the only States in which the cut was larger than for the preceding year, all of the other States showing decreases ranging from 1 per cent in Pennsylvania to 34 per cent in Kentucky. The oak cut is 32 per cent of the aggregate cut of all hardwoods.

The average value of oak for the year was $31.11 per 1,000 feet, an advance of $6.62 per 1,000, or 27 per cent, over the year before.

TABLE 11.—*Reported production of oak*[1] *lumber, 1918.*

[Computed total production in the United States, 2,025,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	7,403	1,658,714,000	100.0	$31.11
Arkansas	285	237,678,000	14.3	29.14
Tennessee	459	181,712,000	11.0	29.23
West Virginia	357	175,130,000	10.6	35.16
Virginia	865	153,598,000	9.3	26.66
Kentucky	442	113,312,000	6.8	34.32
Mississippi	224	97,495,000	5.9	32.96
North Carolina	613	87,947,000	5.3	26.82
Missouri	294	86,302,000	5.2	24.65
Pennsylvania	580	84,729,000	5.1	33.52
Ohio	417	80,099,000	4.8	38.53
Louisiana	97	77,105,000	4.6	28.47
Indiana	335	65,646,000	4.0	42.78
Alabama	263	29,578,000	1.8	22.76
New York	535	25,405,000	1.5	35.22
Georgia	147	24,529,000	1.5	27.43
All other States (see Summary p. 42)	1,490	138,449,000	8.3	31.43

[1] Commercially the oaks are classed as white and red. The principal commercial oaks are listed below:

White oaks.—White oak (*Quercus alba*) is the white oak common throughout the eastern half of the United States.

Chestnut (or rock) oak (*Quercus prinus*) is found in the Appalachian region.

Post oak (*Quercus minor*) and bur oak (*Quercus macrocarpa*) are common throughout the eastern half of the country.

Overcup oak (*Quercus lyrata*) and cow (or basket) oak (*Quercus michauxii*) are the principal southern white oaks.

Red oaks.—Red oak (*Quercus rubra*) is the red oak common to the eastern part of the United States.

Texan red oak (*Quercus texana*) is the principal red oak sawed in the lower Mississippi Valley.

Pin oak (*Quercus palustris*) is found in the Eastern and Central States.

Scarlet oak (*Quercus coccinea*) is the northern and northeastern red oak.

Yellow (or black) oak (*Quercus velutina*) is common to most States east of the Rocky Mountains.

Willow oak (*Quercus phellos*) is cut mostly in the Southern States.

HEMLOCK.

Hemlock production in 1918 was less by approximately 272,000,000 feet, or 14 per cent, than in 1917. The loss in output in comparison with the preceding year amounted to 12 per cent in Wisconsin, 19 per cent in Michigan, 13 per cent in Washington, 17 per cent in Pennsylvania, and 36 per cent in West Virginia. Washington succeeded Michigan in second place in point of production for all States. The output in Oregon, New Hampshire, and Vermont was larger than in 1917. Wisconsin and Michigan combined furnish 45 per cent of the aggregate cut of hemlock. Washington and Oregon produced 18.6 per cent of the country's total in 1917 and 20.3 per cent in 1918.

The average value of hemlock advanced from $20.78 per 1,000 feet in 1917 to $23.97 in 1918, a higher value by $3.19, or 15 per cent.

TABLE 12.—*Reported production of hemlock*[1] *lumber, 1918.*

[Computed total production in the United States, 1,875,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	2,891	1,696,493,000	100.0	$23.97
Wisconsin	226	498,936,000	29.4	25.26
Washington	101	275,693,000	16.3	17.41
Michigan	179	266,822,000	15.7	24.08
Pennsylvania	308	200,573,000	11.8	28.08
West Virginia	94	85,511,000	5.0	27.87
New York	808	70,159,000	4.1	27.76
Oregon	32	68,159,000	4.0	17.18
Maine	327	62,106,000	3.7	26.32
New Hampshire	195	36,511,000	2.2	26.53
North Carolina	61	31,107,000	1.8	19.79
Tennessee	35	28,982,000	1.7	24.49
Virginia	83	26,286,000	1.6	23.86
Vermont	205	18,366,000	1.1	26.76
Massachusetts	110	10,329,000	.6	24.41
All other States (see Summary p. 42)	127	16,953,000	1.0	23.66

[1] Hemlock (*Tsuga canadensis*) is cut in the Lake States, Northeastern States, and the Appalachian region. Western hemlock (*Tsuga heterophylla*) is manufactured in Washington and Oregon. Black (or western mountain) hemlock (*Tsuga mertensiana*) is cut in small quantities. Carolina hemlock (*Tsuga caroliniana*) is occasionally cut in the Appalachian region.

WESTERN YELLOW PINE.

The 1,707,784,000 feet of western yellow pine reported sawed in 1918 was 157,000,000 feet, or 8 per cent, under the 1917 output. The cut in California was 25 per cent less than in 1917 and that State gave way to Oregon as the leading State in production. California furnished 26 per cent of all the western yellow pine cut in 1917 and but 21 per cent in 1918. The cut in Idaho was practically the same as for the preceding year, and a slightly increased total was shown for both Washington and Montana.

The average value of $20.87 per 1,000 feet for western yellow pine differs from the 1917 average of $19.59 by $1.28, or practically 7 per cent.

TABLE 13.—*Reported production of western yellow pine*[1] *lumber, 1918.*

[Computed total production in the United States, 1,710,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	699	1,707,784,000	100.0	$20.87
Oregon	131	437,452,000	25.6	18.23
California, including Nevada	98	357,351,000	20.9	21.28
Idaho	117	310,582,000	18.2	23.50
Washington	115	220,231,000	12.9	18.28
Montana	62	169,956,000	10.0	21.68
Arizona	19	81,583,000	4.8	24.32
New Mexico	38	69,354,000	4.1	22.66
South Dakota	26	29,033,000	1.7	29.82
Colorado	57	26,427,000	1.5	19.65
All other States (see Summary p. 42)	36	5,815,000	.3	19.56

[1] Western yellow pine (*Pinus ponderosa*) is the one species cut as such.

SPRUCE.

The particular need for spruce for specific war purposes stimulated the production of this species in the Pacific northwest, with the result that the output is slightly in excess of the cut for 1917. Maine has been the leading spruce-producing State for a number of years, the annual output being approximately one-third of the country's entire cut, but the State dropped into third position in 1918 with its production amounting to but about one-fifth of the total cut. The scarcity of labor probably had something to do with this condition, since but 252 mills reported operating in 1918 in comparison with 298 mills in 1917. Washington's cut was 78,000,000 feet and Oregon's cut 95,000,000 feet in excess of 1917, or an increase of 39 per cent and 79 per cent, respectively. The combined cut of the two States formed one-half of the aggregate cut of the country. West Virginia's output declined 34 per cent.

The high price paid for airplane stock was offset by the lower prices which were necessary to move the large volume of lower grades, so that the average value reached but $28.65 per 1,000 feet, an advance of $4.24 per 1,000 feet, or 17 per cent over the 1917 figure.

TABLE 14.—*Reported production of spruce*[1] *lumber, 1918.*

[Computed total production in the United States, 1,125,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	1,172	980,561,000	100.0	$28.65
Washington	60	275,826,000	28.1	23.91
Oregon	35	215,828.000	22.0	27.03
Maine	252	206,208,000	21.0	33.26
West Virginia	16	45,258,000	4.6	38.27
New Hampshire	109	44,779,000	4.6	33.01
North Carolina	10	31,912,000	3.3	36.25
Vermont	197	31,530,000	3.2	30.67
New York	141	25,433,000	2.6	33.92
Minnesota	72	18,907,000	1.9	28.13
California	8	16,663,000	1.7	20.75
Colorado	54	16,269,000	1.7	20.72
Wisconsin	40	13,009,000	1.3	30.88
Idaho	18	12,820,000	1.3	23.30
Michigan	65	7,523,000	.8	29.79
All other States (see Summary, p. 42)	95	18,596,000	1.9	25.38

[1] Red spruce (*Picea rubra*) is the principal species cut in the Northeastern States and the Appalachian region.
Sitka spruce (*Picea sitchensis*) is the principal species cut in Oregon and Washington.
Black spruce (*Picea mariana*) is cut in limited quantities in the Northeastern States.
White spruce (*Picea canadensis*) is cut in the Lake States.
Engelmann spruce (*Picea engelmanni*) is cut in the Rocky Mountain region.

MAPLE.

The production of maple shared in the general slump in output. The reported cut of 696,986,000 feet was 105,000,000 feet, or 13 per cent below that of 1917. In Michigan, where more than 40 per cent of the country's total is cut, production dropped 63,000,000 feet, or 18 per cent from the previous year. Production in New York and Ohio was slightly greater than in 1917.

A higher average mill value was obtained in 1918 than in 1917, the average value of $29.05 in 1918 being an increase of $5.89 per 1,000 feet, or 25 per cent.

TABLE 15.—*Reported production of maple*[1] *lumber, 1918.*

[Computed total production in the United States, 815,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	3,659	696,986,000	100.0	$29.05
Michigan	178	287,231,000	41.2	29.93
Wisconsin	256	141,151,000	20.3	26.97
West Virginia	171	58,009,000	8.3	33.85
New York	699	46,691,000	6.7	31.02
Pennsylvania	392	35,324,000	5.1	27.09
Ohio	321	28,443,000	4.1	27.17
Indiana	269	19,582,000	2.8	32.64
Vermont	169	11,449,000	1.6	27.98
Arkansas	69	11,286,000	1.6	24.13
All other States (see Summary, p. 42)	1,135	57,820,000	8.3	25.43

[1] Sugar (or hard) maple (*Acer saccharum*) is cut principally in the Northern States.
Silver (or soft) maple (*Acer saccharinum*) is also cut in the Northern States.
Red (or soft) maple (*Acer rubrum*) is the principal species cut in the Southern States.
Mountain maple (*Acer spicatum*) and striped maple (*Acer pennsylvanicum*) are cut in the Eastern States.
Oregon maple (*Acer macrophyllum*) is cut in the Pacific Coast States.

GUM.

The cut of red gum in recent years, when the production of other woods declined, either increased or underwent little or no change. In 1918, however, the reported total production of 651,545,000 feet was 79,000,000 feet below the total cut in 1917, or 11 per cent. In Arkansas, in which State approximately one-third of the aggregate output of all States is sawed, the decrease in cut amounted to 15 per cent. The decline was shared in by all of the States with the exception of Alabama, where a slightly increased output advances the State from sixth to fifth place in rank of production.

The average value of $23.21 is an increase above the 1917 average of $19.56 of $3.65 per 1,000 feet, or 19 per cent.

TABLE 16.—*Reported production of gum*[1] *lumber, 1918.*

[Computed total production in the United States, 765,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	1,604	651,545,000	100.0	$23.21
Arkansas	239	196,359,000	30.1	22.64
Mississippi	185	148,538,000	22.8	26.62
Louisiana	82	104,514,000	16.0	22.02
Tennessee	187	56,198,000	8.6	23.14
Alabama	90	29,439,000	4.5	20.90
Missouri	57	24,037,000	3.7	22.72
Texas	51	16,448,000	2.5	19.53
South Carolina	30	15,576,000	2.4	21.06
Virginia	104	11,036,000	1.7	18.61
Kentucky	46	9,151,000	1.4	22.09
North Carolina	107	8,136,000	1.3	18.10
Georgia	35	7,723,000	1.2	21.74
Oklahoma	6	6,871,000	1.1	23.70
All other States (see Summary, p. 42)	385	17,519,000	2.7	24.15

[1] Red (or sweet) gum (*Liquidamber styraciflua*) is the only species that goes into red-gum lumber. Commercial sap gum is the sapwood of the red gum.

CYPRESS.

The falling off in cypress production was more marked than for any other one wood. The decrease in reported production was 339,000,000 feet, or 37 per cent. The reported cut in 1918 was 578,026,000 feet. The cut in Louisiana, in which State 51 per cent of the country's cypress was produced, declined from 509,659,000 feet in 1917 to 296,986,000 feet in 1918, or 42 per cent. Florida's cut was 85,376,000 feet in 1918, or 49 per cent less than the 166,857, 000 feet of the year before. South Carolina ranked third among the cypress-producing States in 1917, with a production of 59,107,000 feet. In 1918 the cut dwindled to 28,898,000 feet, or half as much as the year before, and the State dropped into fifth place. In 1918, the number of mills reporting totaled 587 in comparison with 654 for the preceding year.

The average value of cypress took an upward turn of 28 per cent from the average of $23.92 in 1917 to $30.56 in 1918, an increase of $6.64 per 1,000 feet.

TABLE 17.—*Reported production of cypress*[1] *lumber, 1918.*

[Computed total production in the United States, 630,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	587	578,026,000	100.0	$30.56
Louisiana	91	296,986,000	51.2	30.60
Florida	33	85,376,000	14.8	34.69
Georgia	32	41,836,000	7.2	30.90
Arkansas	123	40,638,000	7.0	26.56
South Carolina	28	28,898,000	5.0	33.62
Missouri	45	22,256,000	3.9	24.48
Mississippi	61	17,711,000	3.1	30.52
Tennessee	55	13,581,000	2.4	26.05
North Carolina	53	13,001,000	2.3	24.13
Virginia	20	6,008,000	1.1	31.27
All other States (see Summary, p. 42)	46	11,735,000	2.0	27.19

[1] Bald cypress (*Taxodium distichum*) is the one species cut as such.

REDWOOD.

Redwood production was reduced 44,000,000 feet from the reported total of 487,458,000 feet in 1917, a decrease of 9 per cent. Forty mills reported cutting redwood in 1918 and but 36 mills the year before. The statistics given are believed to cover practically all of the redwood cut.

The average mill value of redwood was $21 in 1917 and $24.30 in 1918, an advance of $3.30 per 1,000 feet, or 16 per cent.

TABLE 18.—*Reported production of redwood*[1] *lumber, 1918.*

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	40	443,231,000	100.0	$24.30
California	40	443,231,000	100.0	24.30

[1] Redwood (*Sequoia sempervirens*) is the species chiefly cut. Bigtree (*Sequoia washingtoniana*) furnishes a minor part of the redwood production.

CHESTNUT.

The reported total cut of chestnut, amounting to 344,929,000 feet, was a decrease of 10 per cent from the 1917 cut. The decline in West Virginia was 22,000,000 feet, or 21 per cent. That State produces approximately one-fourth of all the chestnut sawed into lumber. Pennsylvania, with an increased output of 3,000,000 feet, or 7 per cent, was the one State to show an advance in 1918 over the year before.

The average value of $27.31 per 1,000 feet reported for chestnut is $5.77, or 27 per cent, over the 1917 value.

TABLE 19.—*Reported production of chestnut*[1] *lumber, 1918.*

[Computed total production in the United States, 400,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	2,515	344,929,000	100.0	$27.31
West Virginia	258	85,123,000	24.7	30.14
North Carolina	182	48,720,000	14.1	24.15
Pennsylvania	482	42,880,000	12.4	27.02
Virginia	188	41,866,000	12.1	25.87
Connecticut	112	28,250,000	8.2	29.24
Tennessee	232	26,741,000	7.8	25.50
Massachusetts	121	17,201,000	5.0	25.87
New York	371	14,115,000	4.1	28.74
Kentucky	198	11,069,000	3.2	25.50
Maryland	91	8,417,000	2.4	25.80
Ohio	139	4,990,000	1.4	27.28
Rhode Island	16	4,516,000	1.3	28.15
New Jersey	49	3,793,000	1.1	32.24
New Hampshire	40	3,659,000	1.1	24.79
Georgia	4	2,668,000	.8	29.32
All other States (see Summary, p. 42)	32	921,000	.3	24.43

[1] Chestnut (*Castanea dentata*) is the only species included in chestnut lumber.

BIRCH.

The quantity of birch reported sawed, totaling 316,101,000 feet, was less by 18 per cent than in 1917. The combined cut of Wisconsin and Michigan forms two-thirds of the aggregate produced in the United States. Wisconsin's cut in 1918 was less than the year before by 47,000,000 feet, or 22 per cent, and that of Michigan by 13,000,000 feet, or 21 per cent. An increased output of 3,000,000 feet in New York over the year before lifted that State from sixth to third on the list of producing States.

The advance in the average value of birch was from $24.07 to $29.94 per 1,000 feet, a difference of $5.87, or 24 per cent.

TABLE 20.—*Reported production of birch*[1] *lumber, 1918.*

[Computed total production in the United States, 370,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	1,842	316,101,000	100.0	$29.94
Wisconsin	226	161,968,000	51.2	30.14
Michigan	131	48,807,000	15.4	30.59
New York	372	21,002,000	6.6	30.32
Maine	137	17,071,000	5.4	32.28
Vermont	197	16,913,000	5.3	29.23
West Virginia	92	15,678,000	5.0	33.87
New Hampshire	106	9,364,000	3.0	27.75
Minnesota	66	7,769,000	2.5	21.95
Pennsylvania	180	5,425,000	1.7	28.16
Massachusetts	65	3,412,000	1.1	23.20
All other States (see Summary, p. 42)	270	8,692,000	2.8	24.64

[1] Yellow birch (*Betula lutea*) is the principal species cut in the Lake States, New England, and New York.

Paper birch (*Betula papyrifera*) and white (or gray) birch (*Betula papulifolia*) are also cut to a limited extent in New England.

Sweet (or cherry) birch (*Betula lenta*) is cut in West Virginia and Pennsylvania.

River (or red) birch (*Betula nigra*) is cut in the Southern States.

LARCH.

The reported cut of larch, known as tamarack in the Lake States and the Eastern States, amounting to 333,243,000 feet, was within 1 per cent of the total for 1917. Montana, which has led in the production of larch, cut 16 per cent less than in 1917, and gave way to Idaho in first place. The output in 1918 in Idaho amounted to 119,941,000 feet, an increase of 20 per cent. Washington mills enlarged their reported output from 34,242,000 feet in 1917 to 48,248,000 feet in 1918, or 41 per cent. The cut in other States was smaller than that reported for the year before.

The average value of larch went from $16.21 to $19.86 per 1,000 feet in 1918, an increase of 23 per cent.

TABLE 21.—*Reported production of larch*[1] *(tamarack) lumber, 1918.*

[Computed total production in the United States, 355,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	492	333,243,000	100.0	$19.86
Idaho	58	119,941,000	36.0	19.50
Montana	34	114,250,000	34.3	20.70
Washington	60	48,248,000	14.5	15.04
Wisconsin	113	16,496,000	4.9	26.25
Oregon	16	12,841,000	3.8	18.17
Minnesota	97	11,890,000	3.6	23.06
Michigan	82	9,348,000	2.8	25.76
All other States (see Summary, p. 42)	32	229,000	.1	26.60

[1] Western larch (*Larix occidentalis*) is the species cut in the Inland Empire and the Pacific Northwest. Tamarack, or larch (*Larix larcina*) is cut in the Lake States and New England States.

BEECH.

The reported total output of beech of 255,440,000 feet was smaller by 23,000,000 feet, or 8 per cent, than the 1917 cut. The production of beech is well distributed among the States, no Commonwealth or region dominating the cut. West Virginia with an increased cut of 3 per cent over the year before displaced Indiana in second position in rank of producing States. The output in New York and New Hampshire was larger than for the year before.

The average mill value for beech of $25.06 was $5.48 per 1,000 feet, or 28 per cent, above the 1917 value.

TABLE 22.—*Reported production of beech[1] lumber, 1918.*

[Computed total production in the United States, 290,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	2,502	255,440,000	100.0	$25.06
Michigan	143	46,181,000	18.1	25.52
West Virginia	148	36,631,000	14.3	26.87
Indiana	281	34,212,000	13.4	26.74
Pennsylvania	239	32,249,000	12.6	25.22
New York	567	31,573,000	12.4	24.96
Ohio	294	23,733,000	9.3	23.82
Kentucky	212	18,438,000	7.2	20.68
Tennessee	119	5,694,000	2.2	22.84
Vermont	113	5,575,000	2.2	25.20
Louisiana	12	4,574,000	1.8	23.03
Virginia	55	3,663,000	1.4	23.76
New Hampshire	55	3,096,000	1.2	25.23
All other States (see Summary, p. 42)	264	9,821,000	3.9	23.83

[1] Beech (*Fagus atropunicea*) is the only species that goes into beech lumber.

YELLOW POPLAR.

Yellow poplar production, which declined 17 per cent in 1917 from 1916, fell off 26 per cent in 1918 from 1917. The cut of 241,963,000 feet reported in 1918 is but little more than one-fourth of the quantity reported cut in 1909. The cut in 1918 slumped 34 per cent from the 1917 figure in West Virginia, 15 per cent in Tennessee, 24 per cent in Kentucky, 8 per cent in Virginia, and 24 per cent in Georgia.

The average mill value for yellow poplar in 1918 was $35.06 per 1,000 feet; in 1917 it was $27.17; so that there was an advance of 29 per cent for the year.

TABLE 23.—*Reported production of yellow poplar[1] lumber, 1918.*

[Computed total production in the United States, 290,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	2,011	241,693,000	100.0	$35.06
West Virginia	216	52,462,000	21.7	39.40
Tennessee	335	41,338,000	17.1	35.55
Virginia	232	34,088,000	14.1	32.59
Kentucky	150	31,940,000	13.2	33.53
Georgia	48	21,538,000	8.9	37.63
North Carolina	230	20,336,000	8.4	29.30
Alabama	124	12,311,000	5.1	27.78
Ohio	154	8,683,000	3.6	43.60
Indiana	140	5,979,000	2.5	41.54
Pennsylvania	128	3,507,000	1.4	32.26
South Carolina	41	2,624,000	1.1	31.17
Mississippi	55	2,318,000	1.0	28.37
Maryland	38	1,857,000	.8	32.67
All other States (see Summary, p. 42)	130	2,712,000	1.1	27.53

[1] Yellow poplar (*Liriodendron tulipifera*) is the only species that goes into poplar lumber.

CEDAR.

Cedar production in the country was 230,476,000 feet in 1918, or 11 per cent smaller than in 1917. The cut in Washington was smaller than the year before by 33,000,000 feet, or 25 per cent; Washington produced 52.6 per cent of all the cedar lumber in the United States in 1917 and 44 per cent in 1918. The cut increased in several States—9 per cent in Oregon, 75 per cent in Idaho, 42 per cent in in Michigan, and slightly in California.

The difference in the species cut in the several regions is responsible for the wide variation in the average value shown for the individual States. In 1917 the average for all States was $19.40; this increased $5.46 per 1,000 feet to $24.86 in 1918, or 28 per cent.

TABLE 24.—*Reported production of cedar[1] lumber, 1918.*

[Computed total production in the United States, 245,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	512	230,476,000	100.0	$24.86
Washington	87	102,379,000	44.0	20.06
Oregon	35	45,797,000	19.9	37.15
Idaho	18	26,810,000	11.6	21.42
California	37	21,358,000	9.3	19.14
Michigan	46	8,481,000	3.7	22.04
Maine	49	6,241,000	2.7	26.34
Tennessee	57	5,748,000	2.5	40.55
Virginia	30	3,326,000	1.4	26.32
North Carolina	30	3,226,000	1.4	32.55
Wisconsin	35	3,220,000	1.4	24.11
All other States (see Summary, p. 42)	88	3,890,000	1.7	35.09

[1] Western red cedar (*Thuja plicata*) is cut in Washington, Oregon, and Idaho.
Port Orford cedar (*Chamæcyparis lawsoniana*) is cut in Oregon.
Yellow cedar (*Chamæcyparis nootkatensis*) is cut in Washington.
Incense cedar (*Libocedrus decurrens*) is cut in California.
Northern white cedar (or arborvitæ) (*Thuja occidentalis*) is cut in the Lake States and the Northeastern States.
White cedar (or juniper) (*Chamæcyparis thyoides*) is cut in the Atlantic Coast States.
Red cedar (*Juniperus virginiana*) and southern red juniper (*Juniperus barbadensis*) is cut in Tennessee, Florida, and Alabama.

TUPELO.

The total reported cut of 201,103,000 feet of tupelo in 1918 was 20 per cent under that of the year before. Louisiana's portion of the total cut increased from 51 per cent in 1917 to 61 per cent in 1918, despite the fact that the State's output was 5,000,000 feet below that of the year before, or 4 per cent. Alabama's cut declined 37 per cent, North Carolina's 32 per cent, and South Carolina's 51 per cent. The cut in Arkansas jumped from 4,788,000 to 8,786,000 feet, or 84 per cent.

A higher average mill value was obtained in 1918 than in 1917, the average value of $22.73 in 1918 being an increase of $4.67 per 1,000 feet, or 26 per cent.

TABLE 25.—*Reported production of tupelo* [1] *lumber, 1918.*

[Computed total production in the United States, 237,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	597	201,103,000	100.0	$22.73
Louisiana	59	122,368,000	60.8	22.96
Alabama	31	16,078,000	8.0	23.56
North Carolina	38	12,399,000	6.2	20.74
Arkansas	53	8,786,000	4.4	21.42
South Carolina	14	8,303,000	4.1	22.95
Tennessee	76	6,311,000	3.1	22.43
Mississippi	45	5,082,000	2.5	23.74
Missouri	34	4,343,000	2.2	21.35
Illinois	9	4,332,000	2.2	23.56
Virginia	44	3,519,000	1.7	23.54
All other States (see Summary, p. 42)	194	9,582,000	4.8	21.60

[1] Tupelo (or cotton gum) (*Nyssa aquatica*) is cut in the Gulf States.
Black gum (or pepperidge) (*Nyssa sylvatica*) is cut in the Atlantic and Central States and is sold both as tupelo and black gum.
Water gum (*Nyssa biflora*) is cut to a small extent in the South Atlantic States.

WHITE FIR.

After several years' continued growth in the production of white fir, the cut of 210,750,000 feet in 1918 was 1 per cent under that of the year before. The manufacture declined 13 per cent in California and Nevada, and 42 per cent in Oregon; it increased 34 per cent in Idaho and 38 per cent in Washington.

The 1918 average value of white fir was $19.61 per 1,000 feet; that of 1917, $17.16. The advance was equivalent to 14 per cent.

TABLE 26.—*Reported production of white fir* [1] *lumber, 1918.*

[Computed total production in the United States, 213,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	210	210,750,000	100.0	$19.61
California (including Nevada)	54	104,778,000	49.7	19.98
Idaho	43	50,070,000	23.8	23.71
Washington	35	32,790,000	15.6	14.67
Oregon	36	11,418,000	5.4	15.25
New Mexico	5	5,913,000	2.8	14.31
Montana	15	4,523,000	2.1	19.96
All other States (see Summary, p. 42)	22	1,258,000	.6	18.22

[1] White fir (*Abies concolor*) is cut only in the west.
Marketed as white fir are:
Grand fir (*Abies grandis*), cut mostly in Idaho and Montana.
Silver fir (*Abies amabilis*), cut chiefly in Washington.
Red fir (*Abies magnifica*), cut chiefly in California.
Alpine fir (*Abies lasiocarpa*), cut chiefly in the northern Rocky Mountain and Cascade Mountain region.

BASSWOOD.

Basswood production, reported as 174,661,000 feet in 1918, was 8 per cent below that of 1917. In Wisconsin the cut was 7 per cent greater than the year before, and the State's proportion of the entire output of the country increased from 35.5 per cent to 41.5 per cent. Michigan's production decreased 22 per cent and West Virginia's 19 per cent.

An increase of $8.04 per 1,000 feet—from $25.96 in 1917 to $34 in 1918—took place in the average mill value for basswood. The increase is 31 per cent.

TABLE 27.—*Reported production of basswood*[1] *lumber, 1918.*

[Computed total production in the United States, 200,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	2,102	174,661,000	100.0	$34.00
Wisconsin	259	72,462,000	41.5	34.68
Michigan	162	29,788,000	17.0	36.04
West Virginia	141	17,195,000	9.9	35.34
New York	539	12,265,000	7.0	33.12
Virginia	57	5,895,000	3.4	36.13
Tennessee	63	5,013,000	2.9	32.00
Indiana	100	4,805,000	2.7	34.13
Ohio	138	4,775,000	2.7	32.34
North Carolina	65	4,718,000	2.7	30.09
Kentucky	65	4,249,000	2.4	28.94
Pennsylvania	140	3,437,000	2.0	29.33
Vermont	117	3,286,000	1.9	32.33
Minnesota	77	2,968,000	1.7	23.11
All other States (see Summary, p. 42)	179	3,805,000	2.2	28.07

[1] Basswood (or linn) (*Tilia americana*) is cut in the Lake States.
White basswood (*Tilia heterophylla*) is cut in the Appalachian Mountain region.
Downy basswood (*Tilia pubescens*) is cut in limited quantity in the Southern States.

ELM.

The reported cut of elm in 1918, amounting to 166,481,000 feet, is 13 per cent smaller than that for the preceding year. The cut in Wisconsin, the leading State in production, was less than 1 per cent smaller than in 1917. A decrease is recorded of 20 per cent in Michigan, 14 per cent in Arkansas, and 25 per cent in Indiana.

The upward trend in prices carried the average mill value from $23.89 in 1917 to $28.19 in 1918, an increase of $4.30, or 18 per cent, per 1,000 feet.

TABLE 28.—*Reported production of elm[1] lumber, 1918.*

[Computed total production in the United States, 195,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill
		Feet b. m.		
United States	2,099	166,481,000	100.0	$28.19
Wisconsin	232	45,889,000	27.6	30.10
Michigan	171	28,841,000	17.3	32.18
Arkansas	91	18,692,000	11.2	25.19
Indiana	222	12,876,000	7.7	30.13
Ohio	230	11,068,000	6.7	28.77
Tennessee	112	10,450,000	6.3	23.68
Missouri	100	9,270,000	5.6	21.81
Mississippi	64	7,238,000	4.3	25.83
New York	339	6,291,000	3.8	27.35
Louisiana	34	4,467,000	2.7	23.85
All other States (see Summary, p. 42)	504	11,399,000	6.8	22.30

[1] White (or soft) elm (*Ulmus americana*) is cut in all of the States east of the Rocky Mountains.
Slippery (or red, or soft) elm (*Ulmus pubescens*) is cut in the same region as white elm.
Cork (or true rock) elm (*Ulmus racemosa*) is cut in the Lake States.
Wing elm (*Ulmus alata*) and cedar elm (*Ulmus crassifolia*) are occasionally cut in the lower Mississippi Valley.

COTTONWOOD.

In line with the reduction generally in the cut of other woods, the reported production in 1918 of 148,327,000 feet of cottonwood represents a falling off of 17 per cent in the output compared with the year before. The decrease amounted to 28 per cent in Mississippi, 39 per cent in Arkansas, and 37 per cent in Louisiana.

The average value of cottonwood went up $2.84 per 1,000 feet—from $23.19 in 1917 to $26.13 in 1918—an advance of 13 per cent.

TABLE 29.—*Reported production of cottonwood[1] lumber, 1918.*

[Computed total production in the United States, 175,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	796	148,327,000	100.0	$26.13
Mississippi	51	34,345,000	23.2	27.36
Arkansas	46	28,281,000	19.0	29.15
Minnesota	83	21,721,000	14.7	17.85
Tennessee	37	15,844,000	10.7	27.81
Louisiana	29	13,436,000	9.1	27.45
Missouri	48	6,114,000	4.1	26.94
Michigan	39	2,892,000	1.9	27.24
Kentucky	27	2,298,000	1.5	28.23
Oklahoma	11	2,180,000	1.5	24.28
Wisconsin	30	2,014,000	1.4	25.85
All other States (see Summary, p. 42)	395	19,202,000	12.9	25.95

[1] Common cottonwood (*Populus deltoides*) is the species most commonly cut east of the Rocky Mountains and more particularly in the lower Mississippi Valley.
Swamp cottonwood (*Populus heterophylla*) is cut in the Mississippi Valley States.
Aspen (or popple) (*Populus tremuloides*) is cut in the Lake States and the Northeastern States, and to a limited extent in the Rocky Mountains and farther west.
Large-toothed aspen (*Populus grandidentata*) is cut in the Lake States and Northeastern States.
Balm of Gilead (*Populus balsamifera*) is cut in the Lake States and Eastern States.
Black cottonwood (*Populus trichocarpa*) is cut in the Pacific Coast States.

ASH.

The reported output of ash in 1918, totaling 147,414,000 feet, was within 7 per cent of the cut for the previous year. In practically every State the production was smaller; the decline in Louisiana amounted to 9 per cent, in Arkansas 7 per cent, in Tennessee 5 per cent, and in Wisconsin 6 per cent, while the output in Indiana was nearly the same as in 1917.

Ash has next to the highest average value of any domestic wood. A 29 per cent increase in the average value took place during the year. The 1917 value was $30.01; the 1918 value, $38.70.

TABLE 30.—*Reported production of ash[1] lumber, 1918.*

[Computed total production in the United States, 170,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	2,826	147,414,000	100.0	$38.70
Louisiana	62	19,497,000	13.2	34.76
Arkansas	102	19,321,000	13.1	39.05
Tennessee	151	12,938,000	8.8	44.05
Wisconsin	162	12,887,000	8.7	32.13
Indiana	195	12,300,000	8.4	50.91
New York	548	8,974,000	6.1	39.49
Ohio	217	7,873,000	5.3	48.97
Mississippi	80	7,250,000	4.9	40.50
West Virginia	107	5,854,000	4.0	43.89
Michigan	134	5,627,000	3.8	33.29
Missouri	54	5,442,000	3.7	35.58
Kentucky	124	4,128,000	2.8	35.24
All other States (see Summary, p. 42)	890	25,323,000	17.2	33.37

[1] Lumber trade practice specifies white ash and brown ash. The former is cut from the white ash tree and the latter from the black ash tree.
Green ash (*Flaxinus lanceolata*) is cut in the Southern States.
White ash (*Flaxinus americana*) is cut in the Central States.
Black ash (*Flaxinus nigra*) is cut in the Lake States and Northeastern States.
Red ash (*Flaxinus pennsylvanica*) is cut in limited quantity in the Eastern States.
Oregon ash (*Flaxinus oregona*) is cut in the Pacific Northwest.

SUGAR PINE.

Decreased manufacture of sugar pine to the extent of 16 per cent took place in 1918 from the year before. The total output reported was 111,800,000 feet. A reduction in the number of active mills is noticeable for both California and Oregon.

The average value of sugar pine was $28.26 per 1,000 feet in 1918, an increase over the 1917 value of $3.57, or 14 per cent.

TABLE 31.—*Reported production of sugar pine[1] lumber, 1918.*

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	54	111,800,000	100.0	$28.26
California	43	108,423,000	97.0	28.52
Oregon	11	3,377,000	3.0	20.14

[1] Sugar pine (*Pinus lambertiana*) is the only species cut as such and is found only in California and southern Oregon.

HICKORY.

Hickory and walnut were the only hardwoods the production of which was greater in 1918 than in 1917. The reported cut of hickory was 89,405,000 feet, an increase of 8 per cent. Contributing to this larger total was an increased cut of 18 per cent in Arkansas, 11 per cent in Tennessee, and 19 per cent in Mississippi and Indiana.

The average mill value of hickory of $37.95 per 1,000 feet was $8.47, or 29 per cent, more than the corresponding figure for 1917.

TABLE 32.—*Reported production of hickory*[1] *lumber, 1918.*

[Computed total production in the United States, 100,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	2,127	89,405,000	100.0	$37.95
Arkansas	122	14,806,000	16.6	39.49
Tennessee	208	12,243,000	13.7	39.48
Mississippi	68	8,764,000	9.8	37.23
West Virginia	158	8,759,000	9.8	32.60
Indiana	217	8,666,000	9.7	42.14
Ohio	260	5,623,000	6.3	41.42
Louisiana	29	5,398,000	6.0	41.74
Kentucky	163	5,103,000	5.7	31.78
Pennsylvania	177	2,982,000	3.3	35.17
Virginia	122	2,666,000	3.0	27.40
Missouri	64	2,466,000	2.8	37.21
North Carolina	91	2,057,000	2.3	33.31
All other States (see Summary, p. 42)	448	9,872,000	11.0	39.45

[1] Several species of hickory are cut, the principal ones being shagbark (*Hicoria ovata*), shellbark (*Hicoria laciniosa*), pignut (*Hicoria glabra*), bitternut (*Hicoria minima*), and mockernut (*Hicoria alba*).

WALNUT.

Stimulated by Government agencies, the production of walnut reached a total of 87,305,000 feet in 1918, an increase of 63 per cent over the 1917 cut. The Missouri mills more than doubled their cut, and the output was larger by 52 per cent in Indiana, 51 per cent in Ohio, and 57 per cent in Tennessee. Four mills in Kansas cut 7,507,000 feet, or nearly 9 per cent of the aggregate production of the country. Mills in 34 States reported the manufacture of walnut.

The average mill value of walnut increased $4.61 per 1,000 feet, or 6 per cent, for the year. The value was $72.99 in 1917 and $77.60 in 1918.

TABLE 33.—*Reported production of walnut*[1] *lumber, 1918.*

[Computed total production in the United States, 100,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	855	87,305,000	100.0	$77.60
Missouri	54	29,277,000	33.5	85.92
Indiana	149	11,941,000	13.6	80.99
Ohio	110	10,071,000	11.5	89.07
Tennessee	108	7,581,000	8.6	58.04
Kansas	4	7,507,000	8.6	59.33
Illinois	20	6,130,000	7.0	82.83
Iowa	22	5,416,000	6.2	78.71
Kentucky	96	5,263,000	6.0	68.48
Virginia	51	1,696,000	2.0	51.23
All other States (see Summary, p. 42)	241	2,423,000	3.0	53.27

[1] Black walnut (*Juglans nigra*) is the only species cut as such.

BALSAM FIR.

Balsam fir lumber production in 1918 declined 13 per cent from the year before, the total reported being 65,402,000 feet. Maine mills milled 57 per cent of the country's total output in 1917 and but 46 per cent in 1918. The cut in this State amounted to 30,161,000 feet and represented a decrease of 30 per cent. The cut was less by 4 per cent in Minnesota, 21 per cent in Michigan, and 17 per cent in Vermont. It was larger by 76 per cent in Wisconsin.

The average mill value of balsam fir jumped from $20.02 in 1917 to $27.27 in 1918. The difference of $7.25 per 1,000 feet was 36 per cent.

TABLE 34.—*Reported production of balsam fir*[1] *lumber, 1918.*

[Computed total production in the United States, 82,000,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	406	65,402,000	100.0	$27.27
Maine	163	30,161,000	46.1	28.98
Minnesota	59	10,814,000	16.5	23.42
Wisconsin	26	10,430,000	16.0	28.33
Michigan	37	6,269,000	9.6	26.59
Vermont	61	3,527,000	5.4	22.76
New Hampshire	32	2,534,000	3.9	27.24
New York	23	1,469,000	2.2	27.46
All other States (see Summary, p. 42)	5	198,000	.3	21.34

[1] Balsam fir (*Abies balsamea*) is the only species cut as such.

SYCAMORE.

Sycamore production, totaling 26,283,000 feet, was 8 per cent smaller than the cut reported for the preceding year. In Arkansas, Indiana, and Tennessee, the three States leading in production, the output was smaller; in most of the other States mills reported a slightly increased cut.

The average mill value for sycamore in 1918 was $23.59 per 1,000 feet, compared with $18.68 in 1917, an advance of 26 per cent.

TABLE 35.—*Reported production of sycamore[1] lumber, 1918.*

[Computed total production in the United States, 30,000 000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	775	26,283,000	100.0	$23.59
Arkansas	54	6,437,000	24.5	23.29
Indiana	157	3,457,000	13.2	29.05
Tennessee	74	3,162,000	12.0	22.12
Missouri	71	2,773,000	10.6	19.48
Ohio	100	1,868,000	7.1	26.80
Illinois	38	1,730,000	6.6	23.04
Mississippi	27	1,714,000	6.5	24.63
Kentucky	93	1,518,000	5.8	21.35
Louisiana	12	1,075,000	4.0	23.98
All other States (see Summary, p. 42)	149	2,549,000	9.7	21.71

[1] Sycamore (*Platanus occidentalis*) is the only species cut as such.

LODGEPOLE PINE.

The aggregate cut of 12,176,000 feet of lodgepole pine was 2 per cent less than the cut in 1917. The mills in Montana reported a smaller output, while those in Colorado, Wyoming, and Utah returned a slightly larger production.

The increase in the average mill value for lodgepole pine was $2.61 per 1,000 feet, or 14 per cent, the average having been $18.34 in 1917 and $20.95 in 1918

TABLE 36.—*Reported production of lodgepole pine[1] lumber, 1918.*

[Computed total production in the United States, 12,500,000 feet.]

State.	Number of active mills reporting.	Quantity reported.	Per cent.	Average value per 1,000 feet f. o. b. mill.
		Feet b. m.		
United States	75	12,176,000	100.0	$20.95
Colorado	22	8,052,000	66.1	20.48
Wyoming	21	2,153,000	17.7	23.39
Utah	11	824,000	6.8	22.16
Montana	6	729,000	6.0	17.78
All other States (see Summary, p. 42)	15	418,000	3.4	20.67

[1] Lodgepole pine (*Pinus contorta*) is the only species cut as such.

MINOR SPECIES.

In Table 37 is shown the quantity reported sawed of a number of woods, both domestic and imported, which have more or less special uses and which are in themselves not important enough to be tabulated and discussed separately. The tabulation also indicates the average value reported and the States in which the several woods were sawed. Mahogany forms the largest single item listed; the production was 17 per cent smaller than in 1917. The reported output of locust was almost 5 times greater and that of Spanish cedar almost 10 times greater in 1918 than in 1917.

TABLE 37.—*Reported production of minor species, 1918.*

[Computed total production in the United States, 60,963,000 feet.]

Kind of wood.	Quantity reported.	Average value per 1,000 feet f. o. b. mill.	States reporting.
	Feet b. m.		
Total	56,079,000	$82.80	
Mahogany	21,474,000	160.62	La., Ky., Calif.
Willow	6,269,000	24.90	La., Miss., Mo., Ark., Tenn., Ohio, Pa., Iowa., N. Y.
Cherry	5,277,000	43.79	W. Va., Pa., N. Y., Tenn., Ind., N. C., Va., Mass., Mich., Ohio, Ky., N. H., Wis., Vt., Conn., La.
Noble fir	5,201,000	18.82	Oreg.
Locust	5,020,000	46.31	N. Y., Tenn., Oreg., Ind., Ark., W. Va., Va., N. C., Pa., Mo., La., N. J., Ky., Miss., Md., Ohio.
Buckeye	3,646,000	29.47	Tenn., N. C., Va., W. Va., Ky., Ohio.
Spanish cedar	2,217,000	87.65	La., Ky., Calif.
Pecan	1,865,000	27.91	La., Ark., Miss., Tenn., Ills.
Magnolia	1,579,000	23.52	Tex., La., Ga.
Hackberry	1,133,000	21.53	Ark., La., Miss., Tenn., Ala., Ohio, Ill., Ind., Mo.
Alder	960,000	15.70	Wash., Oreg., Calif.
Butternut	529,000	30.22	Wis., W. Va., Mass., Ind., Pa., Va., Vt., Mich., N. Y., Tenn., N. C., Ky.
Laurel	300,000	[1] 45.00	Calif.
Red Bay	268,000	21.11	Ga., Miss.
Cucumber	130,000	29.61	W. Va., N. Y., Pa., Md., Ky.
Persimmon	70,000	24.10	S. C., Miss., Ark., Ga., La., Tenn.
Mulberry	40,000	20.63	Ga., Ky.
Hornbean	40,000	60.00	Mass.
Sassafras	31,000	23.19	Mo., Ark., Miss., Ill., Ky., Tenn., Ohio.
Box elder	13,000	25.00	N. C.
Mario	9,000	100.00	Calif.
Chittum	4,000	24.00	N. C.
Holly	3,000	26.67	La., N. C.
Coffee tree	1,000	30.00	Ind.

[1] Arbitrary value assigned.

PRODUCTION OF LATH.

Lath production in the United States decreased 40 per cent in 1918 in comparison with the output in 1917. The 1917 cut was 17 per cent less than that of 1916. The smaller output reflected the light demand and the character of construction work carried on during the year; lath production fluctuates each year with the number and class of buildings put up. The reduction in lath production was general. For each State listed a decrease is noticeable in a comparison of the 1918 figures with those of the year before.

The mills reporting their lath cut in 1918 numbered 909, while in 1917 the number was 1,456. Table 38 shows the number of active mills reporting and the production of each for the last few years.

TABLE 38.—*Reported production of lath, 1916–18.*

State.	Number of active mills reporting.			Quantity reported (number of pieces).		
	1918	1917	1916	1918	1917	1916
United States	909	1,456	1,770	1,362,187,000	2,281,738,000	2,754,688,000
Louisiana	53	68	69	236,543,000	348,806,000	354,551,000
Minnesota	31	45	53	155,905,000	213,092,000	267,788,000
Washington	42	58	64	154,668,000	230,194,000	264,690,000
Wisconsin	75	113	121	122,858,000	185,074,000	218,598,000
Mississippi	27	33	30	81,598,000	133,925,000	162,689,000
Oregon	23	32	46	78,780,000	132,418,000	142,352,000
Idaho	20	22	24	70,494,000	86,264,000	117,365,000
Maine	50	106	139	62,671,000	142,488,000	215,117,000
Florida	22	27	28	55,171,000	97,954,000	85,187,000
Michigan	42	62	80	48,533,000	84,352,000	109,323,000
West Virginia	29	54	80	33,289,000	44,233,000	96,665,000
Arkansas	30	31	30	26,481,000	147,578,000	78,157,000
Alabama	18	31	39	25,227,000	39,685,000	64,922,000
California	10	20	19	22,281,000	37,651,000	30,713,000
Montana	11	16	12	21,903,000	23,332,000	25,522,000
Texas	11	18	20	21,866,000	47,654,000	42,686,000
All other States (see Summary, p. 42)	415	720	916	143,919,000	287,038,000	478,363,000

PRODUCTION OF SHINGLES.

Shingle production showed a decrease in 1918 of 35 per cent from the 1917 figures. The 1917 output was less by 7 per cent than the preceding year. The number of shingles reported produced in 1918 was 5,690,182,000. The number of mills reporting was 1,052, in comparison with 1,619 in 1917 and 1,932 in 1916. The figures would indicate the inactivity of 880 mills which were active in 1916. Washington's output of 4,238,714,000 shingles is three-fourths of the whole number manufactured in the United States. All of the States, with the exception of Tennessee, show a decreased production in 1918. The decline in Washington was 33 per cent from the year before.

TABLE 39.—*Reported production of shingles, 1916–18.*

State.	Number of active mills reporting.			Quantity reported (number of pieces).		
	1918	1917	1916	1918	1917	1916
United States	1,052	1,619	1,932	5,690,182,000	8,696,513,000	9,371,333,000
Washington	158	230	238	4,238,714,000	6,313,364,000	6,739,388,000
Oregon	25	42	50	281,138,000	481,353,000	471,762,000
Louisiana	44	55	53	272,866,000	453,819,000	404,263,000
Michigan	48	69	69	148,565,000	203,907,000	201,171,000
California	20	41	52	146,071,000	261,434,000	348,622,000
Florida	37	49	51	102,725,000	143,792,000	131,795,000
Wisconsin	63	73	73	91,907,000	151,726,000	175,455,000
Maine	100	150	200	87,193,000	166,101,000	217,543,000
Alabama	60	94	113	50,065,000	54,735,000	81,414,000
North Carolina	66	110	135	48,080,000	73,703,000	123,959,000
Georgia	37	116	148	46,395,000	112,430,000	131,763,000
Tennessee	33	45	54	44,760,000	5,167,000	9,176,000
Idaho	4	7	9	32,893,000	52,631,000	79,960,000
Arkansas	35	44	42	25,870,000	59,927,000	45,411,000
All other States (see Summary, p. 42)	322	494	645	72,940,000	162,424,000	209,651,000

LUMBER VALUES.

The average values for lumber shown in Table 40 were determined for each species from the individual reports of mills representing every variation incident to the logging, transportation, manufacture, and sale of lumber. More than one-half of the mills, in reporting their cut, furnished values at which sales were made f. o. b. mill. These reports were scrutinized carefully and the figures are undoubtedly representative.

The table shows the average value of the different woods for specified years from 1907 to 1918, during which period the lumber industry has undergone rather marked vicissitudes. The average value of $24.79 per 1,000 feet for all woods in 1918 is an increase of $4.47, or 22 per cent, over the 1917 average figure. It is the highest value recorded for any one year for which statistics are available. Every wood listed in the table shared in the advance, some to a much greater degree than others, as is revealed in the individual species tables.

TABLE 40.—*Average value per 1,000 feet board measure, by kinds of wood, for specified years, 1907–1918.*

Kind of wood.	1918	1917	1916	1915	1911	1910	1909	1907
All kinds	$24.79	$20.32	$15.32	$14.04	$15.05	$15.30	$15.38	$16.56
Softwoods:								
Yellow pine	24.38	19.00	14.33	12.41	13.87	13.29	12.69	14.02
Douglas fir	18.77	16.28	10.78	10.59	11.05	13.09	12.44	14.12
White pine	30.84	24.81	19.16	17.44	18.54	18.93	18.16	19.41
Western yellow pine	20.87	19.59	14.52	14.32	13.62	14.25	15.39	15.67
Hemlock	23.97	20.78	15.35	13.14	13.59	13.85	13.95	15.53
Spruce	28.65	24.41	17.58	16.58	16.14	16.62	16.91	17.26
Cypress	30.56	23.92	20.85	19.85	20.54	20.51	20.46	22.12
Redwood	24.30	21.00	13.93	13.54	13.99	15.52	14.80	17.70
Larch (tamarack)	19.86	16.21	12.49	10.78	11.87	12.33	12.68	13.99
Cedar	24.86	19.40	15.24	16.10	13.86	15.53	19.95	19.14
White fir	19.61	17.16	12.25	10.94	10.64	11.52	13.10	15.54
Sugar pine	28.26	24.69	16.77	17.40	17.52	18.68	18.14	19.84
Balsam fir	27.27	20.02	16.49	13.79	13.42	14.48	13.99	16.16
Lodgepole pine	20.95	18.34	15.13	13.57	12.41	14.88	16.25	(1)
Hardwoods:								
Oak	31.11	24.43	20.06	18.73	19.14	18.76	20.50	21.23
Maple	29.05	23.16	18.24	15.21	15.49	18.16	15.77	16.84
Gum, red and sap	23.21	19.56	14.64	12.54	12.11	12.26	13.20	14.10
Chestnut	27.31	21.54	17.05	16.17	16.63	16.23	16.12	17.04
Birch	29.94	24.07	19.59	16.52	16.61	17.37	16.95	17.37
Beech	25.06	19.58	16.20	14.01	14.09	14.34	13.25	14.30
Yellow poplar	35.06	27.17	21.89	22.45	25.46	24.71	25.39	24.91
Tupelo	22.73	18.06	13.00	12.25	12.46	12.14	11.87	14.48
Basswood	34.00	25.96	21.05	18.89	19.20	20.94	19.50	20.03
Elm	28.19	23.89	19.46	16.98	17.13	18.67	17.52	18.45
Cottonwood	26.13	23.19	17.42	17.36	18.12	17.78	18.05	18.42
Ash	38.70	30.01	23.85	22.15	21.21	22.47	24.44	25.01
Hickory	37.95	29.48	23.84	23.35	22.47	26.55	30.80	29.50
Walnut	77.60	72.99	42.38	48.37	31.70	34.91	43.79	43.31
Sycamore	23.59	18.68	14.65	13.86	13.16	14.10	14.87	14.58

1 Data not obtained.

DETAILED SUMMARY.

In Table 41 are summarized the data presented in the individual species tables, showing, by States, the number of active sawmills reporting and their cut of each wood, and in addition the production of lath and shingles for 1918.

TABLE 41.—*Active sawmills (cutting 50,000 feet and over) reporting, and reported production of each kind of lumber and of lath and shingles, by States, 1918.*

State.	Number of active mills reporting.	Aggregate softwoods and hardwoods.	Softwoods.		
			Total.	Yellow pine.	Douglas fir.
		Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
United States	14,765	29,362,020,000	24,099,554,000	9,941,997,000	5,819,141,000
Alabama	690	1,134,393,000	1,042,098,000	1,037,659,000	
Arizona	19	82,511,000	82,511,000		438,000
Arkansas	612	1,327,393,000	782,874,000	742,236,000	
California and Nevada	153	1,277,084,000	1,275,132,000		219,267,000
Colorado	114	54,632,000	54,520,000		2,917,000
Connecticut	128	57,022,000	12,868,000	2,000,000	
Delaware	25	5,200,000	3,167,000	3,137,000	
Florida	191	862,580,000	851,420,000	765,912,000	
Georgia	481	463,472,000	397,904,000	352,682,000	
Idaho	173	802,529,000	802,219,000		72,658,000
Illinois	94	36,459,000	932,000	15,000	
Indiana	358	185,619,000	100,000		
Iowa	57	13,025,000	10,000		
Kansas and Nebraska	9	8,280,000	5,000		
Kentucky	464	246,656,000	26,282,000	9,165,000	
Louisiana	310	3,158,736,000	2,783,833,000	2,486,847,000	
Maine	476	570,846,000	542,208,000		
Maryland	199	66,378,000	32,031,000	30,223,000	
Massachusetts	227	151,217,000	119,133,000	2,840,000	
Michigan	271	801,967,000	345,107,000		
Minnesota	203	911,453,000	872,573,000		
Mississippi	601	1,786,082,000	1,466,604,000	1,448,893,000	
Missouri	343	241,039,000	64,318,000	42,062,000	
Montana	98	335,811,000	335,344,000		34,906,000
New Hampshire	271	304,999,000	272,635,000	200,000	
New Jersey	70	15,755,000	4,159,000	3,655,000	
New Mexico	47	85,215,000	85,215,000		9,938,000
New York	1,023	328,841,000	157,569,000	365,000	
North Carolina	1,192	1,066,839,000	868,710,000	782,027,000	
Ohio	449	190,920,000	586,000	93,000	
Oklahoma	83	172,294,000	149,324,000	147,494,000	
Oregon	476	2,708,955,000	2,695,302,000		1,898,080,000
Pennsylvania	719	445,313,000	227,464,000	1,726,000	
Rhode Island	16	12,250,000	5,523,000	50,000	
South Carolina	352	483,009,000	445,444,000	416,536,000	
South Dakota	26	29,033,000	29,033,000		
Tennessee	725	492,225,000	93,802,000	37,474,000	
Texas	244	1,215,192,000	1,172,754,000	1,172,154,000	
Utah	67	8,837,000	8,753,000		927,000
Vermont	266	123,558,000	79,312,000		
Virginia	1,222	769,544,000	500,265,000	454,015,000	
Washington	455	4,602,469,000	4,599,859,000		3,578,831,000
West Virginia	370	598,194,000	136,207,000	2,537,000	
Wisconsin	358	1,122,068,000	668,319,000		
Wyoming	38	6,126,000	6,126,000		1,179,000

TABLE 41.—*Active sawmills (cutting 50,000 feet and over) reporting, and reported production of each kind of lumber and of lath and shingles, by States, 1918*—Continued.

State.	Softwoods—Continued.					
	White pine.	Western yellow pine.	Hemlock.	Spruce.	Cypress.	Redwood.
	Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
United States	1,968,474,000	1,707,784,000	1,696,493,000	980,561,000	578,026,000	443,231,000
Alabama					2,855,000	
Arizona	20,000	81,583,000		360,000		
Arkansas					40,638,000	
California and Nevada		357,351,000	4,061,000	16,663,000		443,231,000
Colorado		26,427,000		16,269,000		
Connecticut	8,597,000		2,247,000			
Delaware					10,000	
Florida					85,376,000	
Georgia	2,684,000		702,000		41,836,000	
Idaho	208,749,000	310,582,000	204,000	12,820,000		
Illinois					917,000	
Indiana						
Iowa	8,000					
Kansas and Nebraska						
Kentucky	3,299,000		7,631,000	20,000	5,467,000	
Louisiana					296,986,000	
Maine	237,466,000		62,106,000	206,208,000		
Maryland	442,000		1,300,000		56,000	
Massachusetts	99,377,000		10,329,000	6,174,000		
Michigan	46,664,000		266,822,000	7,523,000		
Minnesota	830,439,000		360,000	18,907,000		
Mississippi					17,711,000	
Missouri					22,256,000	
Montana	4,207,000	169,956,000		6,773,000		
New Hampshire	188,569,000		36,511,000	44,779,000		
New Jersey	73,000		107,000			
New Mexico	10,000	69,354,000				
New York	59,842,000		70,159,000	25,433,000		
North Carolina	7,437,000		31,107,000	31,912,000	13,001,000	
Ohio	155,000		333,000			
Oklahoma					1,830,000	
Oregon	2,322,000	437,452,000	68,159,000	215,828,000		
Pennsylvania	24,615,000		200,573,000	371,000		
Rhode Island	5,365,000		8,000			
South Carolina					28,898,000	
South Dakota		29,033,000				
Tennessee	8,017,000		28,982,000		13,581,000	
Texas					600,000	
Utah		4,257,000		2,481,000		
Vermont	25,722,000		18,366,000	31,530,000		
Virginia	9,410,000		26,286,000	1,210,000	6,008,000	
Washington	65,856,000	220,231,000	275,693,000	275,826,000		
West Virginia	2,901,000		85,511,000	45,258,000		
Wisconsin	126,228,000		498,936,000	13,009,000		
Wyoming		1,558,000		1,207,000		

TABLE 41.—*Active sawmills (cutting 50,000 feet and over) reporting, and reported production of each kind of lumber and of lath and shingles, by States, 1918.*—Continued.

State.	Softwoods—Continued.					
	Larch.	Cedar.	White fir.	Sugar pine.	Balsam fir.	Lodgepole pine.
	Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
United States	333,243,000	230,476,000	210,750,000	111,800,000	65,402,000	12,176,000
Alabama		1,584,000				
Arizona			110,000			
Arkansas						
California and Nevada		21,358,000	104,778,000	108,423,000		
Colorado			855,000			8,052,000
Connecticut		24,000				
Delaware		20,000				
Florida		132,000				
Georgia						
Idaho	119,941,000	26,810,000	50,070,000			385,000
Illinois						
Indiana		100,000				
Iowa	2,000					
Kansas and Nebraska		5,000				
Kentucky		700,000				
Louisiana						
Maine	26,000	6,241,000			30,161,000	
Maryland		10,000				
Massachusetts	25,000	333,000			55,000	
Michigan	9,348,000	8,481,000			6,269,000	
Minnesota	11,890,000	163,000			10,814,000	
Mississippi						
Missouri						
Montana	114,250,000		4,523,000			729,000
New Hampshire	12,000	30,000			2,534,000	
New Jersey		324,000				
New Mexico			5,913,000			
New York	86,000	215,000			1,469,000	
North Carolina		3,226,000				
Ohio		5,000				
Oklahoma						
Oregon	12,841,000	45,797,000	11,418,000	3,377,000		28,000
Pennsylvania	46,000				133,000	
Rhode Island		100,000				
South Carolina		10,000				
South Dakota						
Tennessee		5,748,000				
Texas						
Utah			264,000			824,000
Vermont	32,000	135,000			3,527,000	
Virginia		3,326,000			10,000	
Washington	48,248,000	102,379,000	32,790,000			5,000
West Virginia						
Wisconsin	16,496,000	3,220,000			10,430,000	
Wyoming			29,000			2,153,000

TABLE 41.—*Active sawmills (cutting 50,000 feet and over) reporting, and reported production of each kind of lumber and of lath and shingles, by States, 1918*—Continued.

State.	Hardwoods.					
	Total.	Oak.	Maple.	Gum, red and sap.	Chestnut.	Birch.
	Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
United States	5,262,466,000	1,658,714,000	696,986,000	651,545,000	344,929,000	316,101,000
Alabama	92,295,000	29,578,000	79,000	29,439,000	74,000	110,000
Arizona	...	...	...	...	...	...
Arkansas	544,519,000	237,678,000	11,286,000	196,359,000	...	2,000
California and Nevada	1,952,000	95,000	...	...	...	...
Colorado	112,000	2,000	...	...	...	...
Connecticut	44,154,000	10,662,000	1,195,000	75,000	28,250,000	1,438,000
Delaware	2,033,000	1,195,000	62,000	182,000	50,000	10,000
Florida	11,160,000	1,337,000	...	4,683,000	...	...
Georgia	65,568,000	24,529,000	305,000	7,723,000	2,668,000	9,000
Idaho	310,000	...	...	...	...	...
Illinois	35,527,000	13,719,000	1,636,000	3,064,000	26,000	36,000
Indiana	185,519,000	65,646,000	19,582,000	2,908,000	173,000	389,000
Iowa	13,015,000	2,701,000	495,000	...	...	91,000
Kansas and Nebraska	8,275,000	149,000	7,000	...	...	...
Kentucky	220,374,000	113,312,000	3,898,000	9,151,000	11,069,000	634,000
Louisiana	374,903,000	77,105,000	48,000	104,514,000	...	...
Maine	28,638,000	4,036,000	2,975,000	...	10,000	17,071,000
Maryland	34,347,000	15,889,000	2,472,000	2,214,000	8,417,000	670,000
Massachusetts	32,084,000	6,284,000	1,947,000	...	17,201,000	3,412,000
Michigan	456,860,000	6,212,000	287,231,000	...	...	48,807,000
Minnesota	38,880,000	2,654,000	397,000	...	...	7,769,000
Mississippi	319,478,000	97,495,000	3,847,000	148,538,000	...	10,000
Missouri	176,721,000	86,302,000	6,091,000	24,037,000	5,000	135,000
Montana	467,000	...	...	...	...	...
New Hampshire	32,364,000	9,247,000	5,038,000	...	3,659,000	9,364,000
New Jersey	11,596,000	6,059,000	374,000	540,000	3,793,000	56,000
New Mexico	...	...	...	...	...	...
New York	171,272,000	25,405,000	46,691,000	160,000	14,115,000	21,002,000
North Carolina	198,129,000	87,947,000	6,887,000	8,136,000	48,720,000	2,096,000
Ohio	190,334,000	80,099,000	28,443,000	1,521,000	4,990,000	201,000
Oklahoma	22,970,000	12,135,000	185,000	6,871,000	...	25,000
Oregon	13,653,000	1,888,000	3,135,000	...	...	...
Pennsylvania	217,849,000	84,729,000	35,324,000	793,000	42,880,000	5,425,000
Rhode Island	6,727,000	1,808,000	188,000	...	4,516,000	40,000
South Carolina	37,565,000	5,777,000	1,635,000	15,576,000	...	...
South Dakota	...	...	...	...	...	...
Tennessee	398,423,000	181,712,000	7,719,000	56,198,000	26,741,000	1,738,000
Texas	42,438,000	18,918,000	30,000	16,448,000	...	1,000
Utah	84,000	...	...	...	...	...
Vermont	44,246,000	2,217,000	11,449,000	...	583,000	16,913,000
Virginia	269,279,000	153,598,000	6,432,000	11,036,000	41,866,000	1,001,000
Washington	2,610,000	...	743,000	...	...	...
West Virginia	461,897,000	175,130,000	58,009,000	1,379,000	85,123,000	15,678,000
Wisconsin	453,749,000	15,465,000	141,151,000	...	...	161,968,000
Wyoming	...	...	...	...	...	...

TABLE 41.—*Active sawmills (cutting 50,000 feet and over) reporting, and reported production of each kind of lumber and of lath and shingles, by States, 1918.*—Continued.

State.	Hardwoods—Continued.						
	Beech.	Yellow poplar.	Tupelo.	Basswood.	Elm.	Cottonwood.	Ash.
	Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*
United States	255,440,000	241,693,000	201,103,000	174,661,000	166,481,000	148,327,000	147,414,000
Alabama	560,000	12,311,000	16,078,000	32,000	180,000	1,785,000	917,000
Arizona	...	...	...	...	...	...	...
Arkansas	690,000	103,000	8,786,000	119,000	18,692,000	28,281,000	19,321,000
California and Nevada	...	...	...	...	...	1,500,000	...
Colorado	...	...	...	...	...	110,000	...
Connecticut	414,000	450,000	40,000	188,000	107,000	146,000	514,000
Delaware	70,000	252,000	82,000	...	...	5,000	31,000
Florida	...	300,000	1,151,000	...	...	1,626,000	1,537,000
Georgia	244,000	21,538,000	2,210,000	47,000	184,000	777,000	2,897,000
Idaho	...	...	...	...	...	310,000	...
Illinois	708,000	98,000	4,332,000	101,000	1,833,000	584,000	600,000
Indiana	34,212,000	5,979,000	1,075,000	4,805,000	12,876,000	914,000	12,300,000
Iowa	...	...	...	507,000	1,836,000	1,676,000	149,000
Kansas and Nebraska	...	...	...	...	52,000	337,000	6,000
Kentucky	18,438,000	31,940,000	1,138,000	4,249,000	805,000	2,298,000	4,128,000
Louisiana	4,574,000	21,000	122,368,000	23,000	4,467,000	13,436,000	19,497,000
Maine	1,406,000	123,000	...	1,095,000	157,000	460,000	1,305,000
Maryland	913,000	1,857,000	124,000	677,000	30,000	32,000	301,000
Massachusetts	1,532,000	97,000	...	226,000	21,000	164,000	864,000
Michigan	46,181,000	200,000	2,000	29,788,000	28,841,000	2,892,000	5,627,000
Minnesota	10,000	...	...	2,968,000	2,742,000	21,721,000	615,000
Mississippi	498,000	2,318,000	5,082,000	1,000	7,238,000	34,345,000	7,250,000
Missouri	11,000	167,000	4,343,000	73,000	9,270,000	6,114,000	5,442,000
Montana	...	...	...	...	...	467,000	...
New Hampshire	3,096,000	438,000	...	675,000	62,000	131,000	638,000
New Jersey	174,000	155,000	15,000	13,000	9,000	...	69,000
New Mexico	...	...	...	...	...	...	...
New York	31,573,000	71,000	1,000	12,265,000	6,291,000	979,000	8,974,000
North Carolina	984,000	20,336,000	12,399,000	4,718,000	22,000	437,000	1,655,000
Ohio	23,733,000	8,683,000	300,000	4,775,000	11,068,000	1,001,000	7,873,000
Oklahoma	...	...	9,000	12,000	202,000	2,180,000	241,000
Oregon	...	...	...	...	...	1,259,000	1,821,000
Pennsylvania	32,249,000	3,507,000	21,000	3,437,000	1,066,000	97,000	3,870,000
Rhode Island	22,000	50,000	...	...	2,000	3,000	66,000
South Carolina	...	2,624,000	8,303,000	...	319,000	1,249,000	1,832,000
South Dakota	...	...	...	...	...	...	...
Tennessee	5,694,000	41,338,000	6,311,000	5,013,000	10,450,000	15,844,000	12,938,000
Texas	2,000	...	2,145,000	16,000	82,000	1,016,000	1,171,000
Utah	...	...	...	...	...	84,000	...
Vermont	5,575,000	187,000	3,000	3,286,000	733,000	689,000	2,567,000
Virginia	3,663,000	34,088,000	3,519,000	5,895,000	366,000	450,000	1,610,000
Washington	...	...	...	...	...	884,000	47,000
West Virginia	36,631,000	52,462,000	1,266,000	17,195,000	589,000	30,000	5,854,000
Wisconsin	1,583,000	...	...	72,462,000	45,889,000	2,014,000	12,887,000
Wyoming	...	...	...	...	...	...	...

TABLE 41.—*Active sawmills (cutting 50,000 feet and over) reporting, and reported production of each kind of lumber and of lath and shingles, by States, 1918*—Continued.

State.	Hardwoods—Continued.					
	Hickory.	Walnut.	Sycamore.	Minor species.	Lath.	Shingles.
	Feet b. m.	*Feet b. m.*	*Feet b. m.*	*Feet b. m.*	*Pieces.*	*Pieces.*
United States	89,405,000	87,305,000	26,283,000	56,079,000	1,362,187,000	5,690,182,000
Alabama	913,000	18,000	202,000	19,000	25,227,000	50,065,000
Arizona					17,337,000	250,000
Arkansas	14,806,000	335,000	6,437,000	1,624,000	26,481,000	25,870,000
California and Nevada				357,000	22,281,000	146,071,000
Colorado						186,000
Connecticut	647,000	7,000	16,000	5,000	570,000	325,000
Delaware	90,000	4,000			20,000	
Florida	511,000	15,000			55,171,000	102,725,000
Georgia	1,741,000	17,000	321,000	358,000	19,083,000	46,395,000
Idaho					70,494,000	32,893,000
Illinois	905,000	6,130,000	1,730,000	25,000	8,000	
Indiana	8,666,000	11,941,000	3,457,000	596,000	235,000	
Iowa	122,000	5,416,000	17,000	5,000		
Kansas and Nebraska	1,000	7,707,000	16,000			
Kentucky	5,103,000	5,263,000	1,518,000	7,430,000	1,887,000	2,015,000
Louisiana	5,398,000	222,000	1,075,000	22,155,000	236,543,000	272,866,000
Maine					62,671,000	87,193,000
Maryland	436,000	46,000	250,000	19,000	278,000	3,374,000
Massachusetts	166,000	16,000		154,000	342,000	317,000
Michigan	774,000	110,000	135,000	60,000	48,533,000	148,565,000
Minnesota	3,000	1,000			155,905,000	36,000
Mississippi	8,764,000	17,000	1,714,000	2,361,000	81,598,000	18,431,000
Missouri	2,466,000	29,277,000	2,773,000	215,000	3,618,000	967,000
Montana					21,903,000	5,825,000
New Hampshire	2,000	1,000		13,000	2,235,000	776,000
New Jersey	233,000	57,000	9,000	40,000	2,312,000	3,045,000
New Mexico					15,206,000	30,000
New York	944,000	25,000	9,000	2,767,000	3,863,000	4,066,000
North Carolina	2,057,000	233,000	58,000	1,444,000	10,894,000	48,080,000
Ohio	5,623,000	10,071,000	1,868,000	85,000	1,492,000	140,000
Oklahoma	387,000	85,000	638,000		10,743,000	85,000
Oregon				5,550,000	78,780,000	281,138,000
Pennsylvania	2,982,000	160,000	105,000	1,204,000	18,476,000	3,856,000
Rhode Island	27,000	5,000				
South Carolina	180,000	1,000	30,000	39,000	7,913,000	5,208,000
South Dakota					1,216,000	24,000
Tennessee	12,243,000	7,581,000	3,162,000	3,741,000	7,685,000	44,760,000
Texas	1,671,000	6,000	35,000	897,000	21,866,000	17,746,000
Utah					350,000	1,397,000
Vermont	11,000	8,000		25,000	1,252,000	3,254,000
Virginia	2,666,000	1,696,000	593,000	800,000	16,902,000	1,160,000
Washington				936,000	154,668,000	4,238,714,000
West Virginia	8,759,000	800,000	115,000	2,967,000	33,289,000	44,000
Wisconsin	108,000	34,000		188,000	122,858,000	91,907,000
Wyoming					2,000	383,000

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 846

Contribution from the Bureau of Chemistry
CARL L. ALSBERG, Chief

Washington, D. C. PROFESSIONAL PAPER June 5, 1920

EXAMINATION OF FROZEN EGG PRODUCTS AND INTERPRETATION OF RESULTS

By H. W. Redfield[1]

CONTENTS.

OBJECT OF INVESTIGATION.

The preparation of frozen egg products is universally recognized as an excellent means of conserving eggs which can not be sold in the shell as a first-grade product. So extensive has the business become that 19,286,396 pounds of this material were held in storage on January 1, 1920. Careful studies of frozen egg products, by M. E. Pennington and her colleagues,[2] have included studies of the character of the raw material, the equipment and operation of breaking rooms, and the quality of the product sent into commerce. As a result there has been a marked improvement in the selection of the raw materials used and of the processes of manufacture, with a consequent improvement in the quality of the finished products. The examination of these products has been attended with what was suspected of being a disparity of results when material of the same

[1] The investigation discussed in this bulletin was conducted by the author with the assistance of the following members of the Bureau of Chemistry: M. K. Jenkins, E. A. Read, J. H. Bornmann, G. G. De Bord, W. F. Duncan, L. D. Elliott, H. W. Houghton, W. R. North, G. C. Swan, and H. B. Switzer.

[2] U. S. Dept. Agr., Bur. Chem. Circ. 98 (1912); U. S. Dept. Agr. Buls. 51 (1914), 224 (1916), 39 (1918), 663 (1918).

quality was analyzed in different laboratories. The present investigation was undertaken in order to critically study these methods, and to ascertain whether they might be so standardized as to give concordant results when a number of analysts examined the same product simultaneously. A further object was to learn whether the results of the standardized methods would truly reflect the known quality of carefully prepared samples.

PLAN OF INVESTIGATION.

Since the great bulk of frozen egg products is prepared in the Middle West, it seemed advisable to have the samples prepared in that section. Moreover, it appeared that valuable information could be obtained by preparing samples in different geographical locations, as Michigan or Minnesota, where the eggs while in the shell would have been transported and held under fairly cool climatic conditions, Illinois or Indiana, where the climatic conditions would be somewhat less favorable, and Kansas or Missouri, where the weather would be hot. It was planned to ship these samples for examination to a central point where all the analysts were assembled, in order to eliminate as completely as possible all variable factors. Difficulties in transportation in 1917 made it doubtful as to whether frozen egg samples shipped from a distance would arrive in proper condition for analysis at a central point. For this reason a trip was made to egg-breaking plants in the States named, to ascertain whether eggs were reaching any one large concentrating and breaking center from the same general sources of supply as those used in the other locations, and to learn whether railroad transportation of samples could be depended upon. It was found that shipping frozen egg samples in small lots from outlying points to any central location would be a precarious undertaking and inadvisable. It was found also that in one concentrating center eggs were being received constantly from all of the important producing States, in many instances after long railroad hauls. For that reason, those in charge of the investigation decided to prepare the samples in August, when eggs are recognized as being of the poorest quality, in this concentrating center where checks, dirties, and current receipts were being received from distant points, with the attendant possibilities of deterioration. Thus, samples made from the lowest grade eggs which might legitimately be used for food purposes were assured. It was further determined that the samples should be examined in the same city in which they were prepared, in order to eliminate all railroad transportation.

A series of samples was prepared from the different grades made commercially, allowing the breakers to follow their usual system of grading; a similar series in which the grading was done by members of the Bureau of Chemistry; and a series including a composite sample of each class of eggs considered inedible, in so far as they were obtainable. Records of the eggs used in making these samples were kept. The preparation of each type of sample was repeated in as many different factories, using different raw material, as many times as possible.

PRELIMINARY INVESTIGATION.

In order that all the analysts might have a good working knowledge of the methods of examination before assembling for the analysis of the frozen samples, and to obtain data on fresh eggs of high quality and on storage eggs, they were requested to carry out the following procedure in their home laboratories during the early summer:

1. On five different days, each laboratory shall obtain a representative sample of absolutely fresh eggs. These shall be opened aseptically according to the method described, the yolks and whites shall be thoroughly mixed together under aseptic conditions, and the mixture shall be subjected to bacteriological, chemical, physical, and microscopical examination.
2. On five different days, each laboratory shall obtain a representative sample of absolutely fresh eggs. These shall be opened aseptically according to the method described, and the yolks and whites separated. The thoroughly mixed yolks and the thoroughly mixed whites shall each be subjected to bacteriological, chemical, physical, and microscopical examination.
3. On five different days, each laboratory shall obtain a representative sample of eggs which have been in cold storage, but which are still considered edible, and shall proceed as under No. 1.
4. On five different days, each laboratory shall obtain a representative sample of eggs which have been in cold storage, but which are still considered edible, and shall proceed as under No. 2.

RESULTS OF PRELIMINARY INVESTIGATION.

The results of this part of the investigation are given in Tables 1 to 7, which also include data obtained by one of the laboratories in the examination of some May eggs transported from Tennessee and Ohio to the Atlantic seaboard, and there opened under commercial conditions.

TABLE 1.—*Results of examination of whole egg from approximately 24 eggs, opened and mixed as soon after being laid as possible.*

Sample No.	Date analyzed.	Description of sample.	Odor.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol and skatol.	Organisms per gram. Plain agar, 20°C., 5 days.	Organisms per gram. Plain agar, 37°C., 2 days.	Organisms per gram. Confirmed *B. coli.*
				Per cent.	*Per cent.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per cent.*				
E. D.:	1917.												
5411	July 16	Whole egg, "strictly fresh" [1]	Good	25.97	9.32	1.8	....	1.30	0.30	0	0	0	0
5412	July 18	do.[1]	do	26.17	9.62	[2] 2.4	1.6	1.71	.34	0	0	0	0
5416	July 20	do.[1]	do	26.06	9.75	2.0	[3] 3.0	1.21	.33	0	0	0	0
C. D.:													
1	July 30	Whole egg, between 1 and 2 days old	do	26.75	9.96	[4] 3.8	....	1.59	.35	....	....	....	....
2	Aug. 1	do	do	26.46	9.81	[4] 2.8	....	1.46	.31	....	....	....	....
3	Aug. 2	do	do	26.85	9.97	1.6	....	1.47	.34	....	....	....	....
4	Aug. 3	do	do	26.49	10.12	1.8	....	1.61	.34	....	....	....	....
5	Aug. 4	do	do	25.96	9.31	1.5	....	1.48	.36	....	....	....	....
W. D.:													
3972	June 18	Whole egg, laid June 16 and 17	Faint and pleasant.	26.96	10.19	1.0	1.3	1.44	.29	....	....	....	....
3973	June 20	Whole egg, laid June 17	do	26.14	9.38	1.1	1.0	1.28	.30	....	....	....	....
3974	June 22	Whole egg, laid June 20	do	26.28	9.75	1.1	1.4	1.39	.30	....	....	....	....
3975	June 25	Whole egg, laid June 22	do	26.73	10.03	1.2	1.2	1.33	.32	0	....	....	....
4476	June 28	Whole egg, laid June 26	do	26.52	9.92	1.1	.9	1.54	.32	0	....	....	....
A. P. C.:													
6266	....	Whole egg, not over 24 hours old, from a poultry farm.	....	26.90	10.59	1.7	1.2	1.66	.31	....	....	....	....
6270	....	do	....	26.98	10.59	1.5	1.4	1.70	.33	....	....	....	....
6273	....	do	....	26.63	10.07	1.2	1.2	1.72	.30	....	....	....	....
6276	....	do	....	27.19	10.70	1.7	....	....	.30	....	....	....	....
6279	....	do	....	27.00	11.01	1.6	1.3	....	.32	....	....	....	....
F. R.:													
528	....	Whole egg, not over 48 hours old, sold as strictly fresh.[5]	....	26.18	9.97	1.4	....	1.47	.33	....	0	0	....
		Average [6]	....	26.54	10.00	1.5	1.3	1.49	.32	0	0	0	0
		Maximum [6]	....	27.19	11.01	2.0	1.6	1.72	.36	0	0	0	0
		Minimum [6]	....	25.96	9.31	1.0	.9	1.21	.29	0	0	0	0

Formula value: Average=−16.27.

[1] All eggs apparently normal; 23 eggs used.
[2] Too rapid aeration caused loss of acid in receiving flask.
[3] Cloudy solution interfered with nesslerization.
[4] Sodium carbonate carried over as spray.
[5] About one-half of eggs showed beginning incubation. Appeared fresh before candle.
[6] Abnormal figures omitted.

TABLE 2.—*Results of examination of freshly prepared commercial whole egg.*

Sample No.	Date analyzed.	Description of sample.	Odor.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as sodium ethylate.	Reducing sugar as dextrose.	Indol and skatol.	Organisms per gram.		
						Titration.	Nesslerization.				Plain agar, 20° C., 5 days.	Plain agar, 37° C., 2 days.	Confirmed *B. coli.*
F. R.:	1917.			*Per cent.*	*Per cent.*	*Mg. per 100 grams.*		*Cc. per gram.*					
1	May 23	Whole egg, a. m., Tennessee firsts		26.92	9.95	2.0		1.74			1,100,000	550,000	
2	May 23	Whole egg, p. m., Tennessee firsts		26.78	9.73	2.0		1.81			750,000	220,000	
5	May 24	Whole egg, a. m., Tennessee firsts		27.89	10.48	2.0		1.64			900,000	550,000	
6	May 24	Whole egg, p. m., Tennessee firsts		27.37	10.33	1.9		1.72			70,000	17,000	
8	May 25	Whole egg, Ohio dirties		27.51	10.35	1.6		1.91			280,000	140,000	
9	May 25	Whole egg, Tennessee seconds		28.39	10.56	2.3		1.89			2,300,000	350,000	
11	May 28	Whole egg, a. m., Tennessee seconds		27.18	9.66	1.9		1.81			800,000	2,000,000	
12	May 28	Whole egg, p. m., Tennessee seconds		27.84	10.29	2.1		1.91			1,100,000	600,000	
14	May 29	Whole egg, a. m., cracks and dirties		27.49	10.24	1.9		1.66			4,400,000	1,800,000	
15	May 29	Whole egg, p. m., cracks and dirties		28.57	11.20	1.9		1.89			3,100,000	3,700,000	
		Average		27.59	10.28	2.0		1.80			1,500,000	1,000,000	
		Maximum		28.57	11.20	2.3		1.91			4,400,000	3,700,000	
		Minimum		26.78	9.66	1.6		1.66			70,000	17,000	

Formula value: Average = −7.18.

TABLE 3.—*Results of examination of yolk from approximately 48 eggs opened, separated, and mixed as soon after being laid as possible.*

Sample No.	Date analyzed.	Description of sample.	Odor.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose.	Indol and skatol.	Organisms per gram. Plain agar, 20° C., 5 days.	Organisms per gram. Plain agar, 37° C., 2 days.	Organisms per gram. Confirmed *B. coli*.
				Per cent.	*Per cent.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per cent.*				
E. D.:	1917.												
5421	July 23	Yolk "strictly fresh"	Good	48.95	24.94	2.9	[1] 1.5	1.81	0.16	0			
5422	July 25	do	do	50.24	26.97	2.6	[1] 6.2	1.68		0			
5424	July 27	do	do	50.15	26.33	[2] 1.1	[2] 1.1	1.71	.11	0			
C. D.:													
1	July 30	Yolk, between 1 and 2 days old	do	47.32	24.89	[3] 4.6		1.76	.19				
2	Aug. 1	do	do	48.31	25.50	[3] 3.7		1.68	.18				
3	Aug. 2	do	do	47.88	25.13	2.8		1.62	.19				
4	Aug. 3	do	do	50.17	26.75	3.1		1.71	.18				
5	Aug. 4	do	do	50.04	26.33	2.6		1.56	.19				
W. D.:													
4477	July 3	Yolk, laid July 1	Faint and pleasant.	50.62	28.78	2.5	2.6	1.70	.12				
4478	July 10	Yolk, laid July 8	do	50.90	28.13	2.7	2.8	1.75	.09	0			
4479	July 11	Yolk, laid July 9	do	50.67	27.41	2.6	2.7	1.66	.08				
4480	July 16	Yolk, laid July 13	do	50.24	27.13	2.5	2.6	1.56	.09				
4481	July 17	Yolk, laid July 15	do	50.70	27.43	2.6	1.9	1.44	.11				
A. P. C.:													
6267		Yolk, eggs not over 24 hours old, obtained from a poultry farm.		50.38	27.06	2.5	2.0	1.96	.14				
6271		do		50.07	27.23	2.6	2.1	1.90	.15				
6274		do		50.13	27.29	2.7	2.6	1.90	.12				
6277		do		50.38	27.06	2.7	2.5		.15				
6280		do		50.16	27.74	2.6	2.7		.13				
F. R.:													
529		Yolk, eggs not over 48 hours old; sold as strictly fresh.[4]		46.93	24.49	2.8		1.74	.20		0	0	
		Average [5]		49.69	26.66	2.7	2.5	1.72	.14	0	0	0	
		Maximum [5]		50.90	28.78	3.1	2.8	1.96	.20	0	0	0	
		Minimum [5]		46.93	24.49	2.5	1.9	1.44	.08	0	0	0	
E. D.:													
5417	July 27	Yolk, eggs held 10 days in laboratory	Good	48.52	25.55	7.0	8.9	2.63	.19	0			

Formula value: Average = −36.66.

[1] Cloudy solution interfered with nesslerization.
[2] Too low, incomplete aeration.
[3] Too high, sodium carbonate carried over as spray.
[4] About one-half of eggs showed signs of beginning incubation; appeared fresh before candle.
[5] Abnormal figures omitted.

TABLE 4.—*Results of examination of white from approximately 48 eggs opened, separated, and mixed as soon after being laid as possible.*

Sample No.	Date analyzed.	Description of sample.	Odor.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol and skatol.	Organisms per gram.		
						Titration.	Nesslerization.				Plain agar, 20°C., 5 days.	Plain agar, 37°C., 2 days.	Confirmed *B. coli.*
	1917.			*Per cent.*	*Per cent.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per cent.*				
E. D.:													
5421	July 23	White, "strictly fresh"	Good	12.40		1.1	1.4		0.44	0			
5422	July 25	do	do	12.20	0.02		1.7	0.0	.40	0			
5424	July 27	do	do	12.48	.01	1.2	.6	.0	.31	0			
C. D.:													
1	July 30	White, between 1 and 2 days old	do	12.56	.03	1.6[1]			.46				
2	Aug. 1	do	do	12.77	.01	2.8[1]			.43				
3	Aug. 2	do	do	12.30	.01	.6			.44				
4	Aug. 3	do	do	12.25	.03	.8			.41				
5	Aug. 4	do	do	12.44	.02	(2)			.46				
W. D.:													
4477	July 3	White, laid July 1	Faint and pleasant.	12.83		.2	.2		.38				
4478	July 10	White, laid July 8	do	12.34		.3	Trace		.37	0			
4479	July 11	White, laid July 9	do	12.83		.0	do		.41				
4480	July 16	White, laid July 13	do	12.14		.0	do		.37				
4481	July 17	White, laid July 15	do	12.69		.0	.0		.32				
A. P. C.:													
6268		White, eggs not over 24 hours old, from a poultry farm.		11.99	.09	.9	.5		.40				
6272		do		11.80	.10	.5	.6		.42				
6275		do		12.08	.12	.6	.4		.37				
6278		do		12.43	.07	.8	.5		.44				
6281		do		12.19	.11	.7	.3		.39				
F. R.:													
530		White, eggs not over 48 hours old, sold as strictly fresh.[3]		12.02	.03	.3			.45		0	0	
		Average[4]		12.35	.05	.5	.5	.0	.40	0	0	0	
		Maximum[4]		12.83	.12	1.2	1.7	.0	.46	0	0	0	
		Minimum[4]		11.80	.01	.0	.0	.0	.31	0	0	0	
E. D. 5417	July 27	White, eggs held 10 days in laboratory.		12.43	.02	2.1	1.6	.0	.38	0			

Formula value: Average = —0.32.

[1] Foamed over; too high because sodium carbonate carried over as spray.
[2] Foamed over.
[3] About one-half of eggs showed signs of beginning incubation; appeared fresh before candle.
[4] Abnormal figures omitted.

TABLE 5.—*Results of examination of whole egg from approximately 24 eggs opened and mixed after being held in commercial cold storage.*

Sample No.	Date analyzed.	Description of sample.	Odor	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol and skatol.	Organisms per gram.		
						Titration.	Nesslerization.				Plain agar, 20°C., 5 days.	Plain agar, 37°C., 2 days.	Confirmed *B. coli.*
				Per cent.	*Per cent.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per cent.*				
E. D.:	1917.												
5801	Aug. 1	Stored April 12, 1917; held for 4 months in New York.[1]	Good	27.27	11.25	...	5.1	...	0.37	0	...	...	...
5802	Aug. 2	do	do	28.27	10.42	...	2.9	1.44	.35	0	...	...	...
5803	Aug. 3	do[2]	do	28.43	10.73	2.7	3.4	1.55	.36	0	...	...	...
		Average[3]	...	27.99	10.80	2.7	3.2	1.50	.36	0	...	...	...
A. P. C.:													
6326	...	Held for 7 months in Washington, D. C.[4]	Good	28.23	10.74	2.8	3.1	1.56	.29	0	...	...	...
6329	...	do.[4]	do	28.19	10.77	2.4	2.8	1.60	.30	0	...	...	...
6334	...	do.[4]	do	28.26	10.72	2.9	2.7	1.56	.31	0	...	...	...
6337	...	do.[4]	do	29.19	10.69	2.9	2.8	1.60	.32	0	...	...	...
6340	...	do.[4]	do	28.11	11.00	2.3	2.6	1.68	.34	0	...	...	...
		Average	...	28.20	10.78	2.7	2.8	1.60	.31	0	...	...	...
C. D.:													
1	Dec. 11	Stored April 20, 1917; held for 8 months in Chicago; candled when taken from storage.[6]	Good	28.41	10.69	2.4	(5)	1.79	.37	0	...	...	...
2	Dec. 12	do.[6]	do	28.22	10.49	2.6	2.8	1.85	.36	0	...	...	...
3	Dec. 13	do.[6]	do	28.06	10.55	2.7	2.4	1.88	.33	0	...	...	...
4	Dec. 14	do	do	28.06	10.56	2.6	(5)	1.87	.31	0	...	...	...
5	Dec. 15	do	Strong	26.74	9.96	2.4	(5)	1.93	.28	0	...	...	...
W. D.:													
4488	Nov. 16	Store eggs, mixed colors; held for 8 months in San Francisco.[7]	...	28.09	10.68	3.2	2.6	1.69	.32	...	...	...	...
4489	Nov. 21	Fancy ranch eggs; held for 8 months in San Francisco.[7]	...	27.87	10.56	2.5	2.1	1.76	.33	...	...	...	...
4490	Nov. 21	do.[7]	...	27.41	9.93	2.6	2.3	1.88	.34	...	...	...	...
4491	Nov. 21	do.[7]	...	28.22	10.91	...	2.8	1.82	.34	...	...	...	...
4492	Nov. 26	do.[7]	...	27.72	10.90	2.6	2.6	...	.32	...	...	...	...
		Average[3]	...	27.88	10.52	2.6	2.5	1.83	.33	0	...	...	...

F. R.:													
525	....	May firsts from Iowa; held in Philadelphia from May, 1916, to June, 1917 (13 months).[8]	Not good	29.34	10.88	3.2	....	1.68	.39	....	0	0	....
525a	....	do.[8]	do	....	....	....	....	....	.42	....	....	....	....
		Average	....	29.34	10.88	3.2	....	1.68	.41	....	0	0	....

Formula values: E. D.= −7.35+; A. P. C.= −5.22+; C. D. and W. D.= −3.82+; F. R.= −2.89.

1 Two eggs had cloudy whites; solids developed bad odor when drying.
2 One spot, bloody white.
3 Abnormal figures omitted.
4 Appearance good.
5 Lost by foaming.
6 Shrinkage was marked; whites were viscous.
7 All rigidly candled before stored.
8 Four eggs out of 72 discarded; eggs used looked edible, but considered inedible because had slight odor and taste resembling damp fillers. Shrinkage was marked; yolks somewhat weak and whites slightly tinged with yellow, probably due to diffusion from yolks.

TABLE 6.—*Results of examination of yolk from approximately 48 eggs opened, separated, and mixed after being held in commercial cold storage.*

Sample No.	Date analyzed.	Description of sample.	Odor.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol and skatol.	Organisms per gram. Plain agar, 20°C., 5 days.	Organisms per gram. Plain agar, 37°C., 2 days.	Organisms per gram. Confirmed *B. coli.*
				Per cent.	*Per cent.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per cent.*				
E. D.:	1917.												
5805	Aug. 6	Stored April 12, 1917; held for 4 months in New York.[1]	Good	39.23	19.13	4.0	4.7	1.51	0.26	0	0	0	0
5804	Aug. 7	do.[2]	do.	37.77	18.01	3.6	4.1	1.58	.21	0	650	850	0
5806	Aug 8	do.[3]	do.	41.29	20.58	3.9	3.9	1.49	.22	0	260,000	150,000	0
		Average		39.43	19.24	3.8	4.2	1.53	.23	0	87,000	50,000	0
A. P. C.:													
6327		Held for 7 months in Washington, D. C.[4]	Good	43.66	22.60	4.5	4.4	1.63	.20	0			
6330		do.[4]	do.	42.66	22.05	5.0	4.6	1.69	.20	0			
6332		do.[4]		43.59	22.49	4.9	4.2	1.66	.21	0			
6338		do.[4]	Good	42.52	22.16	4.0	4.3	1.76	.22	0			
6341		do.[4]	do.	41.93	20.84	4.4	4.4	1.80	.24	0			
		Average		42.87	22.03	4.6	4.4	1.71	.21	0			
C. D.:													
1	Dec. 11	Stored April 20, 1917; held for 8 months in Chicago; candled when taken from storage.[5]	Good	41.39	20.70	5.0	(6)	1.81	.23	0			
2	Dec. 12	do.[5]	do.	43.71	22.22	5.2	4.8	1.82	.21	0			
3	Dec. 13	do.[5]	do.	43.64	22.36	4.9	4.5	1.81	.19	0			
4	Dec. 14	do.[5]	do.	43.49	22.47	4.5	(6)	1.77	.21	0			
5	Dec. 15	do.[5]	do.	42.84	21.89	4.6	6.0	1.77	.19	0			
W. D.:													
4493	Nov. 26	Store eggs, mixed colors; held for 8 months in San Francisco.		42.60	22.00	4.8	4.6	1.82	.16				
4494	Dec. 3	Fancy ranch eggs; held for 8 months in San Francisco.[7]		42.32	21.54	4.9	4.4	1.88	.13				
4495	Dec. 3	do.[7]		43.69	22.86	4.8	4.7	1.74	.16				
4496	Dec. 3	do.[7]		44.07	22.83	4.9	5.1	1.87	.17				
4497	Dec. 5	do.[7]		42.71	21.98	5.0	5.1	1.89	.18				
		Average		43.05	22.09	4.9	4.9	1.82	.18	0			

F. R.:													
526	....	May firsts from Iowa; held in Philadelphia from May, 1916, to June, 1917 (13 months).[8]	Not good	43.87	22.74	6.4	....	1.78	.26	....	0	0	....
526a	....	do.[8]	do.	....	....	....	....	....	.31	....	....	....	....
		Average	....	43.87	22.74	6.4	....	1.78	.29	....	0	0	....

Formula values: E. D.= −12.93; A. P. C.= −8.06+; C. D. and W. D.= −4.43+; F. R.= +5.91.

[1] All eggs apparently normal; 6 out of 48 eggs discarded.
[2] One egg had yellowish tint in albumen; remainder apparently as normal as fresh eggs; 3 eggs discarded.
[3] Whites of two eggs had yellowish discoloration; other eggs apparently as normal as fresh eggs; 4 eggs discarded.
[4] Appearance good; in most cases it was hard to separate the yolks from the whites.
[5] Shrinkage was marked; whites were so viscous that it was difficult to completely separate whites from yolks.
[6] Lost by foaming.
[7] All rigidly candled before stored; difficult to completely separate whites from yolks.
[8] Four out of 72 eggs discarded; eggs used looked edible, but considered inedible because had slight odor and taste resembling damp fillers; shrinkage was marked; yolks somewhat weak and whites slightly tinged with yellow, probably due to diffusion from yolks.

TABLE 7.—*Results of examination of white from approximately 48 eggs opened, separated, and mixed after being held in commercial cold storage.*

Sample No.	Date analyzed.	Description of sample.	Odor.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol and skatol.	Organisms per gram.		
						Titration.	Nesslerization.				Plain agar, 20° C., 5 days.	Plain agar, 37° C., 2 days.	Confirmed *B. coli.*
				Per cent.	*Per cent.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*		*Per cent.*				
E. D.:	1917.												
5805	Aug. 6	Stored April 12; held for 4 months in New York.[1]	Good	14.60	0.13		0.6		0.50	0	0	3	0
5804	Aug. 7	do.[2]	do	15.12	.13	0.8	.5		.51	0	34,000	29,000	0
5806	Aug. 8	do.[3]	do	14.18	.03	.8	[4] 1.7		.44	0	290,000	270,000	0
		Average[5]		14.63	.03	.8	.6		.48	0	110,000	100,000	0
A. P. C.:													
6328		Held for 7 months in Washington, D. C.[6]	Good	14.04		.7	.4		.35	0			
6331		do.[6]	do	14.20	.07	.8	.6		.35	0			
6333		do.[6]	do	14.70		.7	.4		.37	0			
6339		do.[6]	do	14.02		.6	.4		.38	0			
6342		do.[6]	do	14.11		.4	.3		.41	0			
		Average		14.21	.07	.6	.4		.37	0			
C. D.:													
1	Dec. 11	Stored April 20; held for 8 months in Chicago; candled when taken from storage.[7]	Good	13.78	.05	.8	([8])		.47	0			
2	Dec. 12	do.[7]	do	14.15	.05	.6	.3		.45	0			
3	Dec. 13	do.[7]	do	13.02	.03	.5	1.3		.42	0			
4	Dec. 14	do.[7]	do	13.92	.03	.6	([8])		.40	0			
5	Dec. 15	do.[7]	do	13.42	.05	.5	([8])		.40	0			
W. D.:													
4493	Nov. 26	Store eggs, mixed colors, held for 8 months in San Francisco.[9]		14.23		0	0		.48				
4494	Dec. 3	Fancy ranch eggs, held for 8 months in San Francisco.[9]		14.38					.42				
4495	Dec. 3	do.[9]		14.64					.42				
4496	Dec. 3	do.[9]		13.89					.42				
4497	Dec. 5	do.[9]		14.07					.42				
		Average[5]		13.96	.04	.5	.5		.43	0			

F. R.:													
527	....	May firsts from Iowa, held in Philadelphia from May, 1916, to June, 1917 (13 months).[10]	Not good	15.54	.03	.4	....	....	.54	....	0	0	....
527a	....	do[10]	do	....	....	....	....	....	.55	....	....	....	....
		Average	....	15.54	.03	.4	....	....	.55	....	0	0	....

Formula values: E. D.= −0.92; A. P. C.= +0.06+; C. D. and W. D.= −2.06+; F. R.= −7.36.

[1] Some yolk in whites; 6 out of 48 eggs discarded.
[2] Some yolk in whites; 1 egg had yellowish tint in albumen; 3 out of 48 eggs discarded.
[3] The whites of 2 eggs had yellowish discoloration; 4 out of 48 eggs discarded.
[4] Cloudy solution interfered with nesslerization.
[5] Abnormal figures omitted.
[6] Appearance good; in most cases it was difficult to separate the whites from the yolks.
[7] Shrinkage was marked; whites were so viscous that it was difficult to completely separate yolks.
[8] Lost by foaming.
[9] All rigidly candled before stored; difficult to completely separate whites from yolks.
[10] Four out of 72 eggs discarded; eggs used looked edible, but considered inedible because had slight odor and taste resembling damp fillers; shrinkage marked; yolks somewhat weak and whites slightly tinged with yellow, probably due to diffusion from yolks.

DISCUSSION OF RESULTS OF PRELIMINARY INVESTIGATION.

The following facts are evident from the data given in Tables 1 to 7, inclusive:

1. The analytical results agree remarkably for all egg samples examined, whether they were purchased and examined in New York, Philadelphia, Washington, Chicago, or San Francisco. This is true for eggs opened as soon after being laid as possible, as well as for those which were held in cold storage for approximately equivalent periods of time. From the regulatory point of view this is important, since it shows that but one basis of judgment as to quality is necessary for the whole of the United States.

2. The limits of variation (Tables 1, 3, and 4) found in the freshest eggs obtainable, opened aseptically in June and July, were as follows:

In whole egg.—For total solids, 25.96 to 27.19 per cent; for ether extract, 9.31 to 11.01 per cent; for ammonia nitrogen, 1 to 2 milligrams per 100 grams; for acidity of fat, 1.21 to 1.72 cc. of N/20 sodium ethylate required per gram; for reducing sugar, 0.29 to 0.36 per cent. No bacteria of any kind were found in any of the samples examined for bacteria.

In yolk.—For total solids, 46.93 to 50.90 per cent; for ether extract, 24.49 to 28.78 per cent; for ammonia nitrogen, 2.5 to 3.1 milligrams per 100 grams; for acidity of fat, 1.44 to 1.96 cc. of N/20 sodium ethylate required per gram; for reducing sugar, 0.08 to 0.20 per cent. No bacteria of any kind were found in any of the samples examined for bacteria.

In white.—For total solids, 11.80 to 12.83 per cent; for ether extract, 0.01 to 0.12 per cent; for ammonia nitrogen, 0.0 to 1.2 milligrams per 100 grams; for reducing sugar, 0.31 to 0.46 per cent. No bacteria of any kind were found in any of the samples examined for bacteria. What is meant by formula values is explained on page 66.

3. The limits of variation (Tables 5, 6, and 7), found in April and May eggs which had been held in cold storage from four to eight months and which were opened aseptically, were as follows:

In whole egg.—For total solids, 27.88 to 28.20 per cent; for ether extract, 10.52 to 10.80 per cent; for ammonia nitrogen, 2.6 to 2.7 milligrams per 100 grams; for acidity of fat, 1.50 to 1.83 cc. of N/20 sodium ethylate required per gram; for reducing sugar, 0.31 to 0.36 per cent. No bacteria of any kind were found in any of the samples examined for bacteria.

In yolk.—For total solids, 39.43 to 43.05 per cent; for ether extract, 19.24 to 22.09 per cent; for ammonia nitrogen, 3.8 to 4.9 milligrams per 100 grams; for acidity of fat, 1.53 to 1.82 cc. of N/20 sodium ethylate required per gram; for reducing sugar, 0.18 to 0.23 per cent. As many as 260,000 bacteria per gram were found.

In white.—For total solids, 13.96 to 14.63 per cent; for ether extract, 0.03 to 0.07 per cent; for ammonia nitrogen, 0.4 to 0.8 milligram per 100 grams; for reducing sugar, 0.37 to 0.48 per cent. As many as 290,000 bacteria per gram were found.

4. The variations in chemical composition (Tables 5, 6, and 7), as would be expected, closely parallel the length of time the eggs were stored.

In whole egg.—The total solids tend to increase slightly; the ether extract to decrease; the ammonia nitrogen to show little change during the first eight months, after which there was a marked increase; the acidity of fat to increase markedly; and the reducing sugar to decrease during the first eight months, after which there was a marked increase.

In yolk.—All of the chemical constituents tend to increase markedly, with the exception of the reducing sugar, which tends to decrease during the first eight months, after which there was a marked increase.

In white.—The total solids tend to decrease slightly, followed by an increase; the ether extract and ammonia nitrogen to show little change; the reducing sugar to decrease and then to increase markedly.

5. The changes in the total solids and ether extract in storage eggs (Tables 5, 6, and 7) are believed to be due primarily to evaporation of moisture through the shell of the egg, and secondarily to decomposition. The changes in ammonia nitrogen, acidity of fat, and reducing sugar are believed to be due primarily to decomposition and secondarily to evaporation. The decrease in the substances measured as reducing sugar by the method employed is believed to be due to a biological decomposition of true reducing sugars, while the marked increase which was noted on longer storage is believed to be due to the breaking down of some of the ovomucoid, which is a glycoprotein and on hydrolysis yields a reducing substance, probably chondroitin-sulphuric acid. This may break down into glucosamine or some similar substance.

6. As showing the deterioration which takes place, especially in the yolk, on long storage, the results obtained from May eggs which had been in cold storage for 13 months (Tables 5, 6, and 7) are of more than passing interest. These eggs looked edible, but were considered inedible because they had a slight odor and taste resembling damp fillers, and were markedly shrunken, with somewhat weak yolks and with whites slightly tinged with yellow, probably due to diffusion from the yolks. The average results obtained were:

In whole egg.—For total solids, 29.34 per cent; for ether extract, 10.88 per cent; for ammonia nitrogen, 3.2 milligrams per 100 grams; for acidity of fat, 1.68 cc. of N/20 sodium ethylate required per gram; for reducing sugar, 0.39 per cent. No bacteria were found in the one sample examined.

In yolk.—For total solids, 43.87 per cent; for ether extract, 22.74 per cent; for ammonia nitrogen, 6.4 milligrams per 100 grams; for acidity of fat, 1.78 cc. N/20 sodium ethylate required per gram; for reducing sugar, 0.29 per cent. No bacteria were found in the one sample examined.

In white.—For total solids, 15.54 per cent; for ether extract, 0.03 per cent; for ammonia nitrogen, 0.4 milligram per 100 grams; for reducing sugar, 0.55 per cent. No bacteria were found in the one sample examined.

7. A comparison of the chemical results obtained from fresh eggs (Tables 1, 3, and 4) with those obtained from eggs which had been held in cold storage (Tables 5, 6, and 7), in which there was a progressive deterioration as the length of time in storage increased, justifies the statement that cold storage does not preserve eggs in the condition in which they were when placed in storage, but merely retards decomposition and deterioration and keeps them in a marketable condition for several months.

8. In sample 5417, ammonia nitrogen of 7 milligrams per 100 grams in the case of the yolk (Table 3) and of 1.6 milligrams per 100 grams in the case of white (Table 4), together with acidity of the fat in the case of yolk of 2.63 cc. of N/20 sodium ethylate required per gram, when compared with the results already cited for fresh eggs (Tables 3 and 4), are of interest as showing how very perishable the egg is and what great changes in composition take place, even while the eggs are still in the shell, when held for as short a period as 10 days without refrigeration.

9. In the case of the whole egg samples (Table 2) prepared commercially during the month of May from firsts, seconds, cracks, and dirties, which, it should be remembered, had been transported over long distances, the average total solids determination of 27.59 per cent and the average ether extract determination of 10.28 are higher than the corresponding average figures of 26.54 and 10 in the case of the strictly fresh egg samples (Table 1), indicating either a shrinkage due to evaporation or the mechanical loss of some of the more watery white. The average ammonia content figure of 2 milligrams per 100 grams and the average acidity of fat figure of 1.80 cc. N/20 sodium ethylate required per gram are higher than the corresponding average figures of 1.5 and 1.49 in the case of fresh eggs, as would be expected, and indicate clearly incipient decomposition. The average figure of 1,500,000 bacteria per gram in these commercial samples, as compared with the lack of bacteria in the fresh whole egg samples prepared aseptically, results from the fact that the eggs composing these samples were taken from commercial breaking stock and were opened under commercial conditions.

10. A comparison of the average results for acidity of fat of 1.49 and 1.72 cc. of N/20 sodium ethylate required per gram, respectively, in whole egg (Table 1) and in yolk (Table 3), both prepared from the freshest eggs obtainable, shows that higher figures were obtained in the case of yolk. Theoretically, the figures should be identical, or very nearly so. It is possible that this difference is due to the removal of substances from the white of the egg by the solvent or by the presence during drying of a relatively large amount of protein in the whole egg. For a tabular summary of this discussion see Table 26 (page 76).

PROGRESS OF THE INVESTIGATION.

PREPARATION OF SAMPLES.

Early in August, 1917, under the supervision of two representatives of the Bureau of Chemistry who have had wide experience in grading eggs both before the candle and while out of the shell, the frozen egg samples were prepared in four commercial houses which are as well equipped as the average breaking plant. In candling and grading the eggs and in preparing the samples representatives of the manufacturers were always present. The manufacturers showed a most gratifying spirit of cooperation throughout the entire investigation. During the preparation of the samples careful records were made of all the available information concerning the past history of the breaking stock and its distribution. As far as possible records were also kept of the number and kinds of eggs which entered each sample. In the case of the samples designated as commercial in Tables 8 to 23 the manufacturers were allowed to follow their own grading, of which the Bureau representatives kept a careful record. In the samples designated as experimental the grading was done by the Bureau of Chemistry representatives.

The Department of Agriculture has taken the position that only two grades of frozen egg material should be prepared—namely, food egg and tanners' egg.[1] Several manufacturers, however, prepare more than one grade of food product. For this reason experimental samples presumably of more than one grade were prepared, but this fact is not to be considered as indicating the approval of the Bureau of Chemistry of such a procedure commercially. In a number of cases as nearly as possible identical types of samples were prepared in several different houses with different raw materials, different equipment, and different breakers.

[1] U. S. Dept. Agr. Bul. 224, p. 21.

EXAMINATION OF SAMPLES.

After the samples had been prepared, frozen, and held in cold storage for several weeks they were examined by three bacteriologists and five chemists. Only one determination of each constituent was made by each chemist, for the reason that four or five chemists performed each determination, averages of which give very reliable results. All bacteriological examinations were made in duplicate.

RESULTS OF EXAMINATION OF SAMPLES.

The results of the examination of the samples are given in Tables 8 to 23. For ease of comparison the histories of the samples and the analytical results have been grouped in the same table. Moreover, all of the samples of the same type have been gathered into each table, and averages have been calculated. These tables are self-explanatory, needing but the few additional comments which are given on pages 55 to 59. Throughout, the use of terms as given in U. S. Department of Agriculture Bulletin 224, page 21, has been followed.

TABLE 8.—*Results of examination of frozen experimental first-grade whole egg containing no sugar or salt (grading dictated).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.								Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
	1917.				1917.	1917.	°F.	°F.			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Lbs.		Hrs.		°F.
29	Aug. 9	R.	Current receipts from Jacksonville, Ill.	Graded from case pack.[1]	Aug. 4	Aug. 9	37	74	2	......	......	......	......	......	......	31	Small power churn.	3	Good.....	−5
34	...do....	J.	Cracks from Jacksonville, Ill.	Cracks[2]	...do....	...do....	37	74	1	......						15	.....do............	1	...do.....	−5
35	...do....	J.	.....do..................	.....do[3]...........	...do....	...do....	37	74	1	......	......	......	......	......	......	10	.....do............	1	...do.....	−5
46	Aug. 10	R.	Cracks from June case pack and from Mt. Vernon, Ill............	.....do[1]...........	Aug. 4, 6	Aug. 4, 6	36	62	1	......	......	......	......	......	......	26	....	3	...do.....	−7
64	Aug. 13	J.	Checks and dirties from Iowa.	Checks and dirties.[4]	Aug. 8, 11	Aug. 11, 13	40	66	1	581	57	57	26	16	1	30	In sample can, with sterile milk stirrer.	2	...do.....	−10
67	...do....	J.	.....do..................	.....do.[5]...........	...do....	...do....	40	66	1	......	......	......	......	......	......	29	.....do............	2	...do.....	−10
70	Aug. 14	R.	Checks and dirties from Wisconsin.	.....do.[1]...........	Aug. 13	Aug. 13, 14	40	62	1	1,265	45	45	37	12	6	27	.....do............	4	...do.....	−10

[1] Included only light hatch spots and stale infertiles.
[2] Included only light hatch spots, with firm yolks and clear whites.
[3] Included only stale infertiles, with firm yolks and clear whites.
[4] Included only eggs separable into yolk and white; all weak; many yolks had enlarged hatch spots; no blood; whites had lost opalescence.
[5] Included only light hatch spots or stale infertiles separable into yolk and white.

TABLE 8.—*Results of examination of frozen experimental first-grade whole egg containing no sugar or salt (grading dictated)*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli*.
	1917.			*Per ct.*	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
29	Aug. 28	B.	Good	27.65	10.72	2.1	2.1	1.94	0.33	0	0	Odor strong; appearance good; color normal; temp. 0° C.	9,900,000	3,000,000			10,000
		D.	Strong			1.9	1.6	1.98	.24	0	0						
		E.	Good	28.06	10.80	1.9	2.1	1.58	.32				9,100,000	4,000,000			10,000
		H.	...do	27.70	10.88	1.6	1.1	1.84									
			Average.	27.80	10.80	1.9	1.7	1.84	.30	0	0		9,500,000	3,500,000			10,000
34	Aug. 29	D.	Good	28.67	11.28	2.1	3.4	1.85				Odor good; appearance good; color normal; temp. +1 ° C.					
		E.	...do	28.56	11.41	2.0	2.1	1.99	.32								
		H.	...do	28.26	11.34	2.1	1.5	1.76	.27	0	0		550,000	140,000	20,000	0	1,000
		S.	...do	28.68	11.54	2.3	2.4		.31	0	0		800,000	250,000	20,000	0	1,000
			Average.	28.54	11.39	2.1	2.4	1.87	.30	0	0		650,000	200,000	20,000	0	1,000
35	...do	B.								0	0	Odor good; appearance good; color normal; temp. +1° C.	11,000,000	5,300,000	290,000	0	10,000
		D.	Good	29.49	11.71	2.3	2.3	1.88									
		E.	...do	29.36	11.87	2.1	2.4	1.95	.30				10,000,000	4,500,000	130,000	0	10,000
		H.	...do	28.41	11.11	2.1	1.6	1.80	.29								
		S.	...do	28.92	11.41	2.2	1.9	2.06	.29								
			Average.	29.05	11.53	2.2	2.2	1.92	.29	0	0		10,500,000	4,900,000	210,000	0	10,000
46	Aug. 31	B.	Good	26.65	10.37	1.9	1.6	1.79	.31	0	0	Odor good; appearance good; color normal; temp. +1° C.	2,900,000	1,700,000	440,000	20,000	100
		D.	...do	27.45	11.15	2.3	2.2	1.99		0	0						

		H.	...do.....	27.66	10.96	2.1	1.8	....	.30	......	......	....	3,600,000	2,300,000	660,000	40,000	100
		S.	...do.....	26.59	10.06	2.1	1.9	1.90	.32	......	......	....	....	....	....	....	....
			Average.	27.09	10.64	2.1	1.9	1.89	.31	0	0	....	3,300,000	2,000,000	550,000	30,000	100
64	Sept. 5	D.	Good....	28.04	11.49	2.3	2.5	1.72	.30	0	0	Odor good; appearance good; color normal; temp. −2° C.	....	....	....	....	....
		E.	...do.....	27.67	10.55	2.3	2.4	1.89	.27	0	0						
		H.	...do.....	27.74	10.52	2.8	2.3	1.79	.30	......	......	....	3,400,000	1,600,000	550,000	100,000	100,000
		S.	...do.....	26.93	10.31	2.3	2.4	1.99	.34	......	......	....	2,900,000	1,400,000	550,000	100,000	100,000
			Average.	27.60	10.72	2.4	2.4	1.85	.30	0	0	....	3,200,000	1,500,000	550,000	100,000	100,000
67	...do...	D.	Good....	27.52	11.08	2.1	[1] 3.2	1.86	......	......	......	Odor good; appearance good; color normal; temp. −2° C.	....	....	....	....	....
		E.	...do.....	27.36	10.10	2.1	2.0	1.94	.28	......	......						
		H.	...do.....	26.93	10.59	2.5	2.3	1.69	.26	0	0	....	850,000	400,000	20,000	0	1,000
		S.	...do.....	27.06	10.43	2.2	2.4	1.93	......	0	0	....	550,000	650,000	20,000	0	1,000
			Average[2]	27.22	10.55	2.2	2.2	1.86	.27	0	0	....	700,000	550,000	20,000	0	1,000
70	Sept. 6	B.	Fair.....	28.15	10.92	2.4	2.5	1.85	.29	......	......	Odor good; appearance good; color normal; temp. −1° C.	....	....	....	....	....
		E.	Good....	27.66	10.94	2.1	2.2	1.90	.30	......	......						
		H.	...do.....	27.63	10.91	2.1	2.4	1.76	.27	0	0	....	130,000	80,000	52,000	0	100
		S.	...do.....	27.19	10.67	2.4	2.9	1.81	.30	0	0	....	110,000	80,000	48,000	0	100
			Average.	27.66	10.86	2.3	2.5	1.86	.29	0	0	....	120,000	80,000	50,000	0	100
Grand average[2]				27.85	10.97	2.2	2.1	1.87	.29	0	0	....	4,000,000	1,800,000	230,000	22,000	17,500
Maximum				29.05	11.53	2.4	2.5	1.92	.31	0	0	....	10,500,000	4,900,000	550,000	100,000	100,000
Minimum				27.09	10.55	1.9	1.7	1.84	.27	0	0	....	120,000	80,000	20,000	0	100

[1] Cloudy solution interfered with nesslerization.

[2] Abnormal figures omitted.

Formula values: Sample 29= −8.39; sample 34= −9.24; sample 35= − 6.07; sample 46= −7.91; sample 64= − 4.11; sample 67= −5.44: sample 70= −5.82.

TABLE 9.—*Results of examination of frozen commercial first-grade whole egg containing no sugar or salt (grading observed and recorded in some).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell. Previous history.	Eggs in shell. Kind of eggs.	Eggs in shell. Date received.	Eggs in shell. Date candled.	Temperature of holding room.	Eggs in breaking room. Temperature of breaking room.	Eggs in breaking room. Number of breakers.	Eggs in breaking room. Number of eggs graded.	Distribution. Used in sample.	Distribution. As first grade.	Distribution. As soft grade.	Distribution. As second grade.	Distribution. As tanner grade.	Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
							° *F.*	° *F.*			*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Lbs.*		*Hrs.*		° *F.*
21	1917. Aug. 8	H.	Current receipts from Jacksonville, Ill.	Graded out from case pack.[1]	1917. Aug. 4	1917. Aug. 8	37	74	4	......	......	......	......	......	......	27	Small power churn	1½	Good.....	− 5
40	Aug. 10	R.	Cracks from June case pack and current receipts from Mount Vernon, Ill.	Cracks and current receipts.[2]	Aug. 4 and 6	Aug. 4 and 6	36	62	1	318	92	92	0	7	1	25	....	2	...do......	− 7
43	...do....	J.	.....do..................	.....do.[3]...........	....do...	....do...	36	62	1	305	89	89	0	8	3	25	....	2½	...do......	− 7
60	Aug. 13	H.	Checks and dirties from Iowa.	Checks and dirties.[4]	Aug. 8 and 11	Aug. 11 and 13	40	66	10	......	......	......	......	......	......	15	Large power churn	......	...do......	−10
74	Aug. 14	J.	Checks and dirties from Wisconsin.	.....do.[5]..........	Aug. 13	Aug. 13 and 14	40	62	1	303	94	94	0	0	6	27	In sample can with sterile milk stirrer.	1	...do......	−10
76	...do....	H.	.....do..................	.....do.[6]...........	....do...	....do...	40	62	7	......	......	......	......	......	......	25	Large power churn	1	...do......	−10

[1] Sampled without warning; therefore, unbiased grading: eggs graded out, but considered too good for tanners, went into sample 22.

[2] Contained hatch spots, 49 per cent; broken yolks, 20 per cent; stale infertiles, 17 per cent; advanced hatch spots, 8 per cent; firm mottled yolks, 3 per cent; slightly stuck yolks, 1 per cent; moldy stuck yolks, 1 per cent; cloudy white, 1 per cent.

[3] Grading approved: contained hatch spots, 77 per cent; stale infertiles, 14 per cent; good broken yolks, 7 per cent; not classified, 2 per cent.

[4] Grading done before arrival of Bureau representatives at factory; therefore, unbiased. Taken from 540-pound batch.

[5] Contained light hatch spots, 56 per cent; broken yolks, 22 per cent; blood rings, 8 per cent; stale infertiles, 3 per cent; mottled yolks, 1 per cent; slightly mottled, 1 per cent; much mottled, 1 per cent; very soft, 1 per cent; unclassified, 1 per cent. One hatch spot had "off" odor.

[6] Sampled without warning; therefore, unbiased grading.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram.				
						Titration.	Nesslerization.						Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, 37° C., 48 hours.	Alkali producers, 37° C., 48 hours.	Confirmed *B. coli*.
	1917.			*Per. ct.*	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*P. ct.*								
21	Aug. 29	D.	Good....	29.06	11.66	2.2	2.5	1.95	....	0	0	Odor good; appearance good; color normal; temperature +1° C.	....	....	....	....	....
		E.	...do.....	29.45	12.17	2.4	2.6	2.00	0.34	0	0						
		H.	...do.....	28.28	11.35	2.2	1.4	1.82	.29	......	......	....	1,800,000	1,100,000	0	0	1,000
		S.	...do.....	28.64	11.51	2.5	2.1	2.02	.29	......	......	....	1,500,000	1,400,000	0	0	1,000
			Average.	28.86	11.67	2.3	2.2	1.95	.31	0	0	....	1,650,000	1,300,000	0	0	1,000
40	Aug. 30	B.	Good....	27.77	10.95	2.5	2.9	....	.30	0	0	Odor good; appearance good; color normal; temperature 0° C.	....	....	....	....	....
		E.	...do.....	28.06	10.93	2.4	2.5	1.74	.31	0	0						
		H.	...do.....	27.93	11.00	2.7	2.2	1.96	.27	......	......	....	5,300,000	2,900,000	77,000	250,000	10,000
		S.	...do.....	28.08	11.05	2.5	2.0	1.78	.33	......	......	....	5,300,000	2,800,000	83,000	270,000	10,000
			Average.	27.96	10.98	2.5	2.4	1.83	.30	0	0	....	5,300,000	2,900,000	80,000	260,000	10,000
43	....do....	B.	Good....	27.28	10.46	2.7	2.8	....	.31	......	......	Odor good; appearance good; color normal; temperature 0° C.	....	....	....	....	....
		E.	...do.....	27.41	10.34	2.1	2.1	1.72	.32	......	......						
		H.	...do.....	26.91	10.35	2.0	1.3	1.77	.28	0	0	....	171,000	20,000	0	0	100
		S.	...do.....	27.57	10.65	2.4	1.9	1.81	.36	0	0	....	150,000	29,000	0	0	100
			Average.	27.29	10.45	2.3	2.0	1.77	.32	0	0	....	160,000	25,000	0	0	100
60	Sept. 4	B.	Good....	28.95	11.78	2.5	2.3	1.82	.32	0	0	Odor good; appearance good; color normal; temperature −2° C.	3,000,000	1,500,000	600,000	50,000	100,000
		D.	...do.....	29.30	11.92	3.0	3.1	1.78	.24	0	0						
		E.	...do.....	28.84	11.96	2.6	2.3	1.89	.31	......	......	....	2,600,000	1,800,000	600,000	49,000	10,000
		H.	...do.....	28.56	11.46	3.0	2.6	....	.29	......	......	....					
			Average.	28.91	11.78	2.8	2.6	1.77	.29	0	0	....	2,800,000	1,700,000	600,000	50,000	55,000

TABLE 9.—*Results of examination of frozen commercial first-grade whole egg containing no sugar or salt (grading observed and recorded in some)*—Con.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram.				
						Titration.	Nesslerization.						Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, 37° C., 48 hours.	Alkali producers, 37° C., 48 hours.	Confirmed *B. coli.*
	1917.			*Per ct.*	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
74	Sept. 4	B.	Good.....	27.57	10.83	2.4	2.4	1.77	0.29	......	......	Odor good; appearance good; color normal; temperature −2° C.	1,200,000	1,000,000	640,000	18,000	1,000
		D.	...do.....	27.84	11.36	2.6	2.3	1.70	.32	......	......						
		E.	...do.....	27.59	10.73	2.4	2.1	1.66	.29								
		H.	...do.....	27.41	10.80	2.7	2.0	1.78	.31	......	......	......	......	......	......	......	......
		S.	......	......	......	......	......	......	......	0	0	......	1,500,000	1,200,000	680,000	22,000	1,000
			Average..	27.60	10.93	2.5	2.2	1.73	.30	0	0	......	1,400,000	1,100,000	660,000	20,000	1,000
76	Sept. 5	B.	......	......	......	......	......	......	......	0	0	Odor good; appearance good; color normal; temperature −2° C.					
		D.	Good.....	28.95	12.21	2.2	[1] 4.2	1.71	.32	......	......		......	......	......	......	......
		E.	...do.....	29.11	11.73	2.4	2.3	......	......	......	......	......	4,200,000	2,000,000	590,000	220,000	100,000
		H.	...do.....	28.74	11.55	2.9	2.7	1.69	.30	......	......	......	......	......	......	......	......
		S.	...do.....	28.50	11.37	2.8	2.7	1.89	.33	......	......	......	4,500,000	2,800,000	530,000	210,000	1,000,000
			Average [2]	28.83	11.72	2.6	2.6	1.76	.32	0	0	......	4,400,000	2,400,000	560,000	210,000	550,000
Grand average [2]......				28.24	11.26	2.5	2.3	1.82	.31	0	0	......	2,600,000	1,600,000	320,000	90,000	100,000
Maximum [2]......				28.91	11.78	2.8	2.6	1.95	.32	0	0	......	5,300,000	2,900,000	660,000	260,000	550,000
Minimum [2]......				27.29	10.45	2.3	2.0	1.73	.29	0	0	......	160,000	25,000	0	0	100

[1] Cloudy solution interfered with nesslerization.

[2] Abnormal figure for ammonia nitrogen content of sample 76 omitted.

Formula values: Sample 21= −7.12; sample 40= −3.70; sample 43= −5.72; sample 60= −3.17; sample 74= −5.16; sample 76= −4.67.

TABLE 10.—*Results of examination of frozen commercial first-grade whole egg containing 1 per cent sugar and 0.7 per cent salt (grading observed in some).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Temperature of breaking room.	Number of breakers.	Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.							
	1917.				1917.	1917.	*°F.*	*°F.*		*Pounds.*		*Hours.*		*°F.*
4	Apr. —	H.	Unknown	Unknown[1]						30	Large power churn			
9	Aug. 3	H.	do	do.[2]						30	do			
11	Aug. 6	R.	Cracks from Fort Dodge, Iowa.	Cracks[3]	Aug. 2	Aug. 6	35	63	16	25	do	1/2	Good	+1
18	Aug. 7	H.	Current receipts from Oklahoma.	Current receipts.[4]	July 27	Aug. 7	35	63	16	25	do	1/3	do	+1
50	Aug. 10	J.	Cracks from June storage pack and Mt. Vernon, Ill.	Cracks[5]	Aug. 4 and 6	Aug. 4 and 6	36	62	5	25	do	3/4	do	−7

[1] First-grade, April pack. Purchased in August.
[2] First-grade packed commercially three days before investigation began.
[3] From 150-pound batch. Contained about 70 per cent hatch spots and 30 per cent infertiles.
[4] Pretended to be through sampling and then took this one for unbiased grading. Contained mostly hatch spots, few weak, many blood rings, and some small embryos.
[5] Grading was not observed by Bureau representatives. Compare with results from dictated grading, using same eggs.

TABLE 10.—*Results of examination of frozen commercial first-grade whole egg containing 1 per cent sugar and 0.5 per cent salt (grading observed in some)*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli*.
				Per ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
4	1917. Aug. 25	B.	Good....	28.44	10.29	2.0	1.8	1.51	[1] 0.38	0	0	Odor good; appearance good; color normal; temperature, −2° C.	360,000	30,000	....	....	100
		D.	...do.....	28.11	10.10	1.8	1.9	2.00	.27	0	0						
		H.	...do.....	27.36	9.56	2.0	1.5	1.55	.33	.....	.....	....					
		S.	...do.....	26.93	9.68	1.4	2.0	1.67	.29	.....	.....	....	320,000	10,000	....	....	100
			Average[2].	27.71	9.91	1.8	1.8	1.68	.30	0	0	....	340,000	20,000	....	....	100
9	...do....	B.	Good....	27.54	10.90	2.7	2.4	1.62	.30	.....	.....	Odor good; appearance good; color normal; temperature, −2° C.	15,500,000	5,000,000	....	....	100,000
		D.	...do.....	29.13	11.51	2.2	2.6	....	....	.....	.....						
		H.	...do.....	29.52	11.65	2.3	2.5	1.69	.29	.....	.....	....					
		S.	...do.....	29.39	11.83	....	2.5	1.76	.25	0	0	....	14,500,000	6,700,000	....	....	100,000
			Average.	28.90	11.48	2.4	2.5	1.69	.28	0	0	....	15,000,000	5,900,000	....	....	100,000
11	Aug. 24	B.	Good....	29.37	11.04	2.6	2.9	1.90	.32	0	0	Odor good; temperature, −2° C.; blood rings; no embryos or molds.	....	....	....	....	....
		E.	...do.....	28.97	10.56	2.2	3.0	1.71	.30	0	0						
		H.	...do.....	29.30	11.05	2.6	3.2	1.77	.31	.....	.....	....	7,000,000	2,600,000	....	....	10,000
		S.	...do.....	29.04	10.68	2.6	2.2	2.01	.30	.....	.....	....	8,500,000	2,700,000	....	....	10,000
			Average.	29.20	10.83	2.5	2.8	1.90	.31	0	0	....	7,800,000	2,700,000	....	....	10,000
18	Aug. 22	B.	Good....	29.61	11.15	2.4	[3] 3.4	1.69	.31	0	0	Odor strong; appearance good; color normal; temperature, 0° C.	....	....	....	....	....
		D.	...do.....	29.79	11.58	[4] 3.1	2.9	1.80	.28	0	0						
		E.	...do.....	28.90	10.87	2.3	2.4	1.77	.28	0	0	....					
		H.	...do.....	28.59	....	2.0	2.4	....	.31	0	0	....	2,700,000	200,000	....	....	10,000
		S.	...do.....	29.96	11.14	2.3	2.7	1.95	.29	0	0	....	3,000,000	400,000	....	....	10,000
			Average[2].	29.37	11.19	2.3	2.6	1.80	.29	0	0	....	2,900,000	300,000	....	....	10,000

50	Sept. 1	B. D.	Fair....	29.10	11.10	2.7	1.7	1.65	.31	0	0	Odor good; appearance good; temperature, 0° C.	....	....	....	....	....
			Good....	29.50	11.40	2.3	....	1.64	.26	0	0						
		E. S.	....	29.42	11.11	2.2	2.2	1.80	.30	......	......	....	6,100,000	1,400,000	750,000	0	1,000,000
			Good....	28.65	10.46	2.4	2.2	1.57	.32	......	......	....	6,500,000	2,600,000	900,000	0	1,000,000
			Average	29.17	11.02	2.4	2.0	1.67	.30	0	0	....	6,300,000	2,000,000	850,000	0	1,000,009
Grand average[3]........				28.89	10.89	2.3	2.4	1.75	.30	0	0	....	6,500,000	2,200,000	850,000	0	220,000
Maximum[2]........				29.37	11.48	2.5	2.8	1.90	.31	0	0	....	15,000,000	5,850,000	850,000	0	1,000,000
Minimum[2]........				27.71	9.91	1.8	1.8	1.67	.28	0	0	....	340,000	20,000	850,000	0	100

[1] Crucible not completely dried. [2] Abnormal figures omitted. [3] Cloudy solution interfered with nesslerization. [4] Alkali carried over mechanically.

Formula values; Sample 4= —10.29; sample 9= —3.63; sample 11= —2.20; sample 18= —6.31; sample 50= —3.82.

TABLE 11.—*Results of examination of frozen experimental soft-grade whole egg containing no sugar or salt (grading dictated).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.								Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution. Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
							F.°	F.°			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Lbs.		Hrs.		° F.
31	1917. Aug. 9	R.	Current receipts from Jacksonville, Ill.	Graded out from case pack.[1]	1917. Aug. 4	1917. Aug. 9	37	74	2	......	......	......	......	......	......	23	Small power churn.	3	Good....	—5
47	Aug. 10	R.	Cracks from June case pack and current receipts from Mount Vernon, Ill.	Cracks and current receipts.[2]	Aug. 4 Aug. 6	Aug. 4 Aug. 6	36	62	1	......	......	......	......	......	......	11	In sample can with sterile milk stirrer.	3	....do....	7
65	Aug. 13	J.	Checks and dirties from Iowa.	Checks and dirties.[3]	Aug. 8 and 11	Aug. 11 and 13	40	66	1	581	26	57	26	16	1	14	....do........	2	....do....	—10
71	Aug. 14	R.	Cracks and dirties from Wisconsin.	Cracks and dirties.[4]	Aug. 13	Aug. 13 and 14	40	66	1	1,265	37	45	37	12	6	26	....do........	4	....do....	—10

[1] Included advanced hatch spots, 47 per cent; weak, 45 per cent; dark yolks, 8 per cent.
[2] Included weak with yolks slightly broken, 79 per cent; mottled firm yolks, 10 per cent; advanced hatch spots, 10 per cent; chocolate yolk, 1 per cent.
[3] Graded out from sample 64. Included 4 per cent of slightly mottled yolks; balance typical weak eggs, stale infertiles and hatch spots, showing no blood.
[4] Graded out from sample 70. Included weak, 71 per cent; mottled firm yolks (heated), 19 per cent; advanced hatch spots, 6 per cent; stale, 2 per cent; dark yolks, 1 per cent; sour, 1 per cent.

TABLE 11.—*Results of examination of frozen experimental soft-grade whole egg containing no sugar or salt (grading dictated)*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli.*
				Per ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
31	1917. Aug. 28	B.	Good....	27.46	10.79	2.5	2.5	1.96	0.28	0	0	Odor good; appearance good; color normal; temp. 0° C.	9,100,000	2,400,000	99,000	0	100,000
		D.	Strong...	27.46	10.88	2.1	2.3	....	.28	0	0						
		E.	Good....	28.05	10.96	2.2	2.4	1.70	.30	0	0	....					
		H.	...do.....	27.51	10.83	....	1.7	1.81	....	0	0	....	9,400,000	2,200,000	100,000	0	100,000
			Average.	27.62	10.87	2.3	2.2	1.82	.29	0	0	....	9,300,000	2,300,000	100,000	0	100,000
47	Aug. 31	B.	Fair.....	28.51	11.46	2.2	1.9	1.85	.31	0	0	Odor good; appearance good; color normal; temp. +1° C.	340,000	90,000	57,000	10,000	1,000
		D.	Good....	27.25	11.38	2.3	2.2	....	.27	0	0						
		H.	...do.....	27.75	11.13	2.1	1.8	....	.25	0	0	....					
		S.	...do.....	27.75	10.91	2.1	2.0	1.82	.30	0	0	....	290,000	120,000	63,000	10,100	100
			Average.	27.82	11.22	2.2	2.0	1.84	.28	0	0	....	320,000	110,000	60,000	10,000	550
65	Sept. 5	D.	Slightly sour.	26.95	10.52	2.3	[1]5.3	1.94	.31	0	0	Odor strong; appearance good; color normal; temp. −2° C.					
		L.	Good....	27.17	10.78	2.3	2.4	1.76	.32	0	0		....	....	....	....	....
		H.	...do.....	27.21	10.50	2.8	1.9	....	.30	0	0	....	....	....	....	....	....
		S.	...do.....	27.70	10.81	2.6	2.8	1.81	.36	0	0.	....	....	....	....	....	....
			Average[2].	27.26	10.65	2.5	2.4	1.84	.32	0	0	....	([2])	([2])	([3])	....	([3])
71	Sept. 6	B.	Strong...	28.21	11.01	2.5	1.9	1.90	.30	0	0	Odor good; appearance good; color normal; temp. −1° C.					
		E.	Good....	28.11	11.25	2.1	2.5	1.95	.30	0	0		....	....	....	....	....
		H.	...do.....	27.59	10.92	2.5	2.4	1.73	....	0	0	....	1,400,000	210,000	130,000	0	100,000
		S.	...do.....	27.22	10.73	2.4	2.4	1.70	.31	0	0	....	1,200,000	120,000	130,000	0	100,000
			Average.	27.78	10.98	2.4	2.3	1.82	.30	0	0	....	1,300,000	170,000	130,000	0	100,000

Grand average[2]	27.62	10.93	2.3	2.2	1.83	.30	0	0	....	3,600,000	850,000	97,000	3,000	67,000
Maximum[2]	27.82	11.22	2.5	2.4	1.84	.32	0	0	....	9,300,000	2,300,000	130,000	10,000	100,000
Minimum[2]	27.26	10.65	2.1	2.0	1.82	.28	0	0	....	320,000	110,000	60,000	0	550

[1] Cloudy solution interfered with nesslerization. [2] Abnormal figures omitted. [3] Sample contaminated.

Formula values: Sample 31= —4.17; sample 47= —7.33; sample 65= —4.21+; sample 71= —6.29.

TABLE 12.—*Results of examination of frozen commercial soft-grade whole egg containing no sugar or salt (grading observed and recorded in some).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.				Eggs in breaking room.									Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
							° F.	° F.			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Lbs.		Hrs.		° F.
13	1917. Aug. 7	R.	Current receipts from Oklahoma.	Current receipts.[1]	1917. July 27	1917. Aug. 7	35	63	4	804	17	77	17	0	6	24	Small hand churn.	2	Good....	+1
45	Aug. 10	J.	Cracks from June case packs and current receipts from Mount Vernon, Ill.	Cracks and current receipts[2].	Aug. 4 and 6	Aug. 4 and 6	36	62	2	635	5	89	5	3	3	8½	In sample can with sterile milk stirrer.	4	...do....	—7
54	Apr.—	H.	Unknown.	Unknown.[3]	....	....	....	....	....	....	....	....	....	....	....	30	....	....	....	....

[1] Graded out from samples 12 and 17. Contained weak yolks, 38 per cent; heavily mottled yolks, 31 per cent; hatch spots, 20 per cent; blood rings, 6 per cent; stale infertiles, 5 per cent.

[2] Graded out from samples 42 and 44. Contained weak yolks, 40 per cent; mottled yolks and cloudy whites, 34 per cent; broken yolks, 12 per cent; firm yolks, 8 per cent; yolks broken by accident, 4 per cent; slightly stuck, 2 per cent.

[3] Soft-grade April pack. Purchased in August.

TABLE 12.—*Results of examination of frozen commercial soft-grade whole egg containing no sugar or salt (grading observed and recorded in some)*—Con.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli*.
	1917.			*Per. ct.*	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
13	Aug. 24	B.	Good....	26.13	10.02	2.6	2.6	....	0.29	....	....	Odor good; appearance good; color normal; temperature −2° C.	....	....	....	....	....
		E.	...do.....	25.21	9.45	2.1	2.7	1.77	.25	0	0						
		H.	...do.....	26.02	10.08	2.4	1.8	1.79	.26	0	0	....	900,000	950,000	....	....	100,000
		S.	...do.....	25.86	9.77	2.4	1.8	1.97	.27	0	0	....	1,100,000	1,100,000	....	....	10,000
			Average.	25.81	9.83	2.4	2.2	1.84	.27	0	0	....	1,000,000	1,000,000	....	....	55,000
45	Aug. 31	B.	Fair.....	27.17	10.43	2.0	1.5	2.01	.33	0	0	Odor strong; appearance good; color normal; temperature +1° C.	3,400,000	4,900,000	0	0	100
		D.	Strong...	27.33	11.11	2.5	2.4	....	.31	0	0						
		H.	Good....	27.51	10.81	2.5	2.2	....	....	....	....	....	....	....	....	....	....
		S.	...do.....	27.39	10.28	2.6	2.1	1.97	.34	....	....	....	4,100,000	4,500,000	0	0	100
			Average.	27.35	10.66	2.4	2.1	1.99	.33	0	0	....	3,800,000	4,700,000	0	0	100
54	Sept. 1	B.	Fair.....	27.71	10.78	2.2	1.5	1.61	.35	....	....	Odor good; appearance good; color normal; temperature 0° C.	150,000	100,000	10,000	0	100
		D.	Good....	27.01	10.30	....	2.0	1.73	28	....	....						
		E.	....	27.51	10.60	1.7	1.8	1.83	.32	....	....						
		H.	Fair....	....	....	....	....	....	....	0	0	....	....	....	....	....	....
		S.	Good....	26.86	9.75	2.2	1.8	1.76	.31	....	....	....	110,000	80,000	10,000	0	100
			Average.	27.27	10.36	2.0	1.8	1.73	.32	0	0	....	130,000	90,000	10,000	0	100
Grand average....				26.81	10.28	2.3	2.0	1.85	.31	0	0	....	1,600,000	1,900,000	5,000	0	18,500
Maximum....				27.35	10.66	2.4	2.2	1.99	.33	0	0	....	3,800,000	4,700,000	10,000	0	55,000
Minimum....				25.81	9.83	2.0	1.8	1.73	.27	0	0	....	130,000	90,000	0	0	100

Formula values: Sample 13= −1.44; sample 45= −3.28; sample 54= −9.88.

TABLE 13.—*Results of examination of frozen whole egg prepared from leakers containing no sugar or salt.*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.								Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
							° F.	° F.			P.ct.	P.ct.	P.ct.	P.ct.	P.ct.	Lbs.		Hrs.		° F.
1	1917. Aug. 6	R.	Cracks from Fort Dodge, Iowa.	Leakers graded out from cracks by 1 candler.[1]	1917. Aug. 2	1917. Aug. 6	35	....	1	......	......	.....	.....	.....	.....	24	In small hand churn.	4	Good	+1
3	...do....	J.	.....do..................	Leakers graded out from cracks by 6 candlers.[2]	...do....	..do.....	35	63	2	360	74	74	0	8	18	22	.....do............	1½	...do.....	+1
30	Aug. 9	J.	Current receipts from Jacksonville, Ill.	Leakers graded out from current receipts by whole candling force.[3]	Aug. 4	Aug. 9	37	74	1	360	80	80	0	8	12	23	In small power churn.	2	...do.....	−5
49	Aug. 10	J.	Cracks from June case pack and current receipts from Mount Vernon, Ill.	Leakers graded out from cracks and current receipts by candlers.[4]	Aug. 4 and 6	Aug. 4 and 6	36	....	....	......	......	.....	.....	.....	.....	24	In sample can with sterile milk stirrer.	1	Musty ...	−7

[1] Broken out in candling room as breaker candled cracks. Bad eggs detected by candling or smell discarded. Breaking and grading done very carefully.

[2] Broken out in breaking room under best conditions. Grading observed. Breaking room discards included moldy, 58 per cent; sour, 12 per cent; mixed rots, 10 per cent; slightly stuck yolks, 9 per cent; green whites, 7 per cent; strong odor, 2 per cent; empty, 2 per cent.

[3] Broken out in breaking room under best conditions. Grading dictated. Fifty-three per cent of the breaking-room discards were moldy.

[4] Broken out directly into cans in candling room by candlers with no other grading than candling.

TABLE 13.—*Results of examination of frozen whole egg prepared from leakers containing no sugar or salt*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli*.
				Per ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per. ct.*								
1	1917. Aug. 23	D.	Strong...	29.91	12.47	......	......	......	......	0	0	Odor strong; appearance good; color normal; temperature, −2° C.	......	......	......	......	......
		E.	...do.....	30.77	12.85	2.2	2.7	1.50	0.31	0	0						
		H.	Good....	30.39	12.63	2.0	2.7	......	.27	0	0	......	13,600,000	2,300,000	......	......	100,000
		S.	...do.....	29.25	12.90	2.4	3.2	1.69	.32	0	0	......	11,900,000	1,400,000	......	......	100,000
			Average.	30.08	12.71	2.2	2.9	1.60	.30	0	0	......	12,800,000	1,900,000	......	......	100,000
3	...do....	D.	Good. Sl.	28.78	11.75	2.9	3.4	......	......	0	0	Odor strong; appearance good; color normal; temperature, −2° C.	......	......	......	......	......
		E.	strong...	29.03	11.50	2.4	2.5	1.51	.32	0	0						
		H.	Good....	28.36	11.46	2.6	2.5	......	......	0	0	......	8,900,000	2,700,000	......	......	100,000
		S.	...do.....	28.55	12.41	2.4	3.1	1.67	.28	0	0	......	9,700,000	2,400,000	......	......	100,000
			Average.	28.68	11.78	2.6	2.9	1.59	.30	0	0	......	9,300,000	2,600,000	......	......	100,000
30	Aug. 28	B.	Good....	30.11	12.49	2.9	2.1	1.72	.28	......	......	Odor good; appearance good; color normal; temperature, 0° C.	......	......	......	......	......
		D.	Strong...	30.01	12.58	2.3	2.4	......	......	......	......						
		E.	Good....	30.87	12.71	2.5	3.3	1.70	.27	0	0	......	1,900,000	1,300,000	4,800	0	1,000
		H.	...do.....	30.22	12.70	......	2.0	1.79	......	0	0	......	2,000,000	1,300,000	5,100	0	1,000
			Average.	30.30	12.62	2.6	2.5	1.74	.28	0	0	......	2,000,000	1,300,000	5,000	0	1,000
49	Sept. 1	B.	Musty...	28.93	11.75	2.6	1.9	1.77	.32	0	0	Odor musty; appearance good; temperature, 0° C.	......	......	......	......	......
		D.	...do.....	29.79	12.46	2.9	3.3	1.74	.24	0	0						
		E.	...do.....	28.59	11.14	2.7	2.7	1.94	.29	0	0	......	10,400,000	600,000	100,000	0	100
		S.	...do.....	29.68	12.03	2.8	2.5	1.90	.33	......	......	......	10,400,000	1,300,000	99,000	0	100
			Average.	29.25	11.85	2.8	2.6	1.84	30	0	0	......	10,400,000	950,000	100,000	0	100

Grand average	29.58	12.24	2.6	2.7	1.69	.30	0	0	....	8,800,000	1,700,000	53,000	0	50,000
Maximum	30.30	12.71	2.8	2.9	1.84	.30	0	0	....	12,800,000	2,600,000	100,000	0	100,000
Minimum	28.68	11.78	2.2	2.5	1.59	.28	0	0	....	2,000,000	950,000	5,000	0	100

Formula values: Sample 1= —11.29; sample 3= —5.94; sample 30 = —7.78; sample 49= —1.76.

TABLE 14.—*Results of examination of frozen experimental first-grade yolk containing no sugar (grading dictated).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.								Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
							°F.	°F.			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Lbs.		Hrs.		°F.
17	1917. Aug. 7	J.	Current receipts from Oklahoma.	Current receipts[1]	1917. July 27	Aug. 7	35	63	2	......	.....	.....	.....	.....	.....	26	Small hand churn.	2	Good.....	+1
44	Aug. 10	J.	From June storage pack and from Mount Vernon, Ill.	Cracks[2]	Aug. 4,6	Aug. 4,6	36	62	1	635	89	89	5	3	3	25	In can with sterile milk stirrer.	3	...do.....	—7

[1] Weak eggs graded out went into sample 13.

[2] Contained 76 per cent hatch spots, 18 per cent infertiles, and 6 per cent unclassified.

TABLE 11.—*Results of examination of frozen experimental first-grade yolk containing no sugar (grading dicated)*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli.*
	1917.			*Per ct.*	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per. gram.*	*Per ct.*								
17	Aug. 24	B.	Good....	43.00	22.83	4.2	4.6	....	0.20	0	0	Odor good; appearance good; color normal; temperature −2° C.					
		E.	...do.....	42.99	22.53	4.3	5.0	1.77	.20	0	0		....	....	....	....	....
		H.	...do.....	43.80	23.15	3.7	2.7	1.79	.18	.....	.....	....	220,000	170,000	....	....	1,000
		S.	...do.....	43.89	23.59	4.0	3.2	1.86	.21	.....	.....	....	260,000	150,000	....	....	1,000
			Average.	43.42	23.03	4.1	3.9	1.81	.20	0	0	....	240,000	160,000	....	....	1,000
44	Aug. 30	B.	Good....	44.20	23.11	4.8	4.5	1.92	.19	.....	.....	Odor good; appearance good; color normal; temperature 0° C.					
		D.	...do.....	....	....	....	....	....	....	0	0		....	....	....	....	....
		E.	...do.....	44.19	23.45	4.0	4.2	1.78	.19	.....	.....	....	....	....	....	....	....
		H.	...do.....	40.47	23.45	4.7	4.9	1.79	.15	.....	.....	....	260,000	210,000	0	0	100
		S.	...do.....	43.90	22.97	4.2	3.4	1.70	.19	.....	.....	....	290,000	330,000	0	0	100
			Average.	43.19	23.25	4.4	4.3	1.80	.18	0	0	....	280,000	270,000	0	0	100
Grand average........				43.31	23.14	4.2	4.1	1.81	.19	0	0	....	260,000	220,000	0	0	550
Maximum........				43.42	23.25	4.4	4.3	1.81	.20	0	0	....	280,000	270,000	0	0	1,000
Minimum........				43.19	23.03	4.1	3.9	1.80	.18	0	0	....	240,000	160,000	0	0	100

Formula values: Sample 17= −14.57; sample 44= −11.30.

TABLE 15.—*Results of examination of frozen commercial first-grade yolk containing no sugar (grading observed or recorded).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.								Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
	1917.				1917.	1917.	° F.	° F.			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Lbs.		Hrs.		° F.
10	Aug. 6	R.	Cracks from Fort Dodge, Iowa.	Cracks [1]	Aug. 2	Aug. 6	35	63	16	......	.....	.....	.....	.....	.....	25	Large power churn.	½	Good	+1
12	Aug. 7	R.	Current receipts from Oklahoma.	Current receipts [2] .	July 27	Aug. 7	35	63	2	804	77	77	17	0	6	26	Small hand churn.	2½	...do.....	+1
20	Aug. 8	R.	Current receipts from Jacksonville, Ill.	Graded out from case pack.[3]	Aug. 4	Aug. 8	37	74	2	849	71	71	0	24	5	24	Small power churn.	2½	...do.....	−5
42	Aug. 10	R.	Cracks from June storage pack and from Mount Vernon, Ill.	Cracks [4]	Aug. 4 and 6	Aug. 4 and 6	36	[illegible]	2	......	.....	.....	.....	.....	.....	25	In can with sterile milk stirrer.	2	...do.....	−7

[1] Contains 31 per cent infertiles and 69 per cent light hatch spots. Grading observed only. Breakers worked as usual.
[2] Graded commercially. Made from 42 per cent hatch spots, 40 per cent infertiles, 9 per cent blood rings, 5 per cent mottled yolks, and 4 per cent weak eggs.
[3] Graded commercially. Made from 44 per cent hatch spots, 40 per cent infertiles, 8 per cent blood rings, 4 per cent weak, 2 per cent mottled yolks, 1 per cent light stuck, and 1 per cent addled.
[4] Graded commercially. Made from 66 per cent hatch spots, 21 per cent infertiles, 8 per cent advanced hatch spots, 4 per cent mottled yolks, and 1 per cent weak.

TABLE 15.—*Results of examination of frozen commercial first-grade yolk containing no sugar (grading observed or recorded)*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram.				
						Titration.	Nesslerization.						Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, 37° C., 48 hours.	Alkali producers, 37° C., 48 hours.	Confirmed *B. coli*.
				Per. ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per. ct.*								
10	1917. Aug. 24	B.	Strong...	42.93	22.37	4.1	4.7	2.05	0.22	0	0	Odor good; appearance good; color normal; temperature, −2° C.	......	......	......	......	......
		E.	Good....	43.29	22.52	4.2	4.5	1.84	.16	0	0						
		H.	...do.....	43.12	22.14	4.2	4.3	2.10	.23	......	......	......	5,500,000	2,400,000	......	......	100,000
		S.	...do.....	43.04	21.69	4.1	3.8	1.87	.20	......	......	......	5,000,000	2,000,000	......	......	100,000
			Average.	43.10	22.18	4.2	4.3	1.97	.20	0	0	......	5,300,000	2,200,000	......	......	100,000
12	...do....	B.	Fair.....	44.12	23.81	4.2	4.4	......	.20	......	......	Odor good; appearance good; color normal; temperature, −2° C.	......	......	......	......	......
		E.	Good....	43.48	23.03	4.2	4.7	1.68	.19	......	......						
		H.	...do.....	44.54	21.42	4.2	2.6	1.98	.19	0	0	......	320,000	90,000	......	......	100
		S.	...do.....	44.35	23.32	4.2	2.9	1.89	.19	0	0	......	220,000	180,000	......	......	100
			Average.	44.12	22.90	4.2	3.7	1.85	.19	0	0	......	270,000	140,000	......	......	100
20	Aug. 29	D.	Good....	44.51	23.42	4.2	5.1	1.93	.19	0	0	Odor good; appearance good; color normal; temperature, +1° C.	......	......	......	......	......
		E.	...do.....	46.69	24.17	3.9	4.0	2.11	.16	0	0						
		H.	...do.....	43.83	23.26	3.9	5.2	1.89	.17	......	......	......	3,100,000	1,100,000	......	......	1,000
		S.	...do.....	44.31	23.40	4.0	3.6	2.04	.14	......	......	......	2,900,000	1,200,000	......	......	1,000
			Average.	44.84	23.56	4.0	4.5	1.99	.17	0	0	......	3,000,000	1,200,000	......	......	1,000

42	Aug. 30	B.	Good	44.73	23.59	4.4	4.8	1.92	.17			Odor good; appearance good; color normal; temperature, 0° C.					
		E.	...do	45.07	23.68	4.1	4.2	1.75	.16								
		H.	...do	44.51	23.82	4.0	4.8	1.88	.16	0	0		1,700,000	380,000			10,000
		S.	...do	44.55	23.66	4.2	3.6	1.79	.19	0	0		1,400,000	360,000			1,000
			Average	44.72	23.69	4.2	4.4	1.84	.17	0	0		1,600,000	370,000			5,500
Grand average				44.19	23.08	4.1	4.2	1.91	.18	0	0		2,500,000	1,000,000			26,500
Maximum				44.84	23.69	4.2	4.5	1.99	:20	0	0		5,300,000	2,200,000			100,000
Minimum				43.10	22.18	4.0	3.7	1.84	.17	0	0		270,000	140,000			100

Formula values: Sample 10= —9.82; sample 12= —13.24; sample 20= —14.24; sample 42= —14.11.

TABLE 16.—*Results of examination of frozen commercial first-grade yolk containing 10 per cent sugar.*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell. Previous history.	Eggs in shell. Kind of eggs.	Size of sample.	How churned.	Date analyzed	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli*.
					Lbs.					*Per ct.*	*Per ct.*	*Mg. per 100 gms.*	*Mg. per 100 gms.*	*Cc. per gram.*	*P. ct.*								
2	1917. Apr. –	H.	Unknown.	Unknown.[1]	30	Large power churn	1917. Aug. 25	B.	Good.	48.48	17.94	3.3	2.7	1.05	[2]0.36	0	0	Odor good; appearance good; color normal; temp. −2° C.					
								D.	...do...	48.33	......	2.6	2.5	......	.30	0	0		....	....	....	....	......
								H.	...do...	48.37	18.07	3.3	2.7	1.22	.29	...	...	....	300,000	28,000	....	....	1,000
								S.	...do...	48.65	17.82	......	3.9	.84	.25	...	...	....	140,000	12,000	....	....	1,000
									Average[4].	48.46	17.94	3.1	3.0	1.04	.28	0	0	....	220,000	20,000	....	....	1,000
5	Aug. 3	H.	...do......	do.[3]......	30	...do.	Aug. 25	B.	Good.	49.26	18.62	4.2	3.4	1.66	.26	...	...	Odor good; appearance good; color normal, temp. −2° C.					
								D.	...do...	48.96	18.78	3.2	3.0	1.37	.29	...	...		....	....	....	....	......
								H.	...do...	49.08	18.94	3.4	3.0	1.20	.26	...	...	....	1,000,000	420,000	....	....	10,000
								S.	...do...	48.92	18.27	3.9	3.2	1.14	.22	0	0	....	900,000	480,000	....	....	10,000
									Average..	49.06	18.65	3.7	3.2	1.19	.26	0	0	....	950,000	450,000	....	....	10,000
							Grand average[4]......			48.76	18.35	3.4	3.1	1.13	.27	0	0	....	690,000	240,000	....	....	5,500
							Maximum[4].........			49.06	18.65	3.7	3.2	1.19	.28	0	0	....	950,000	450,000	....	....	10,000
							Minimum[4].........			48.46	17.94	3.1	3.0	1.04	.26	0	0	....	220,000	20,000	....	....	1,000

[1] First grade April pack; purchased in August.
[3] First grade August pack. Prepared three days before investigation began.
[2] Crucible not completely dried.
[4] Omitting abnormal figure.

Formula values: Sample 2= −14.55; sample 5= −8.54.

TABLE 17.—*Results of examination of frozen experimental second-grade whole egg containing no sugar or salt (grading dictated).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.								Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
	1917.				1917.	1917.	°F.	°F.			P.ct.	P.ct.	P.ct.	P.ct.	P.ct.	Lbs.		Hrs.		°F.
32	Aug. 9	R.	Current receipts from Jacksonville, Ill.	Graded out from case pack.[1]	Aug. 4	Aug. 9	37	74	2	......	......	......	......	......	......	15	In small power churn.	3	Slightly sour.	−5
48	Aug. 10	R.	Cracks from June case pack and current receipts from Mount Vernon, Ill.	Cracks and current receipts.[2]	Aug. 4 and 6	Aug. 4 and 6	36	62	1	......	......	......	......	......	......	5	In sample can with sterile milk stirrer.	3	....	−7
66	Aug. 13	J.	Checks and dirties from Iowa.	Checks and dirties[3]	Aug. 8 and 11	Aug. 11 and 13	40	66	1	581	16	57	26	16	1	10	....do............	2	Sour.....	−10
72	Aug. 14	R.	Cracks and dirties from Wisconsin.	Cracks and dirties[4]	Aug. 13	Aug. 13 and 14	40	62	1	1,265	12	45	37	12	6	14	....do............	4	Strong...	−10

[1] Graded out from samples 29 and 31. Included very weak, mottled, and doubtful eggs.
[2] Graded out from samples 46 and 47. Included very weak yolks, 42 per cent; mottled yolks, 34 per cent; not classified, 13 per cent; cloudy whites, 9 per cent; advanced hatch spots, 2 per cent.
[3] Graded out from samples 64 and 65. Included slightly stuck yolks, 33 per cent; very mottled yolks, 20 per cent; very weak, 13 per cent; sour, 10 per cent; good whites (yolks discarded), 8 per cent; moldy cracks with normal contents, 5 per cent; blood rings, 5 per cent; mixed rots (early stage), 4 per cent; light green whites, 2 per cent.
[4] Graded out from samples 70 and 71. Included very weak, 51 per cent; heavily mottled yolks, 23 per cent; cloudy whites, 12 per cent; blood rings (bleached), 7 per cent; strong stale odor, 6 per cent; sour, 1 per cent.

TABLE 17.—*Results of examination of frozen experimental second-grade whole egg containing no sugar or salt (grading dictated)*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli.*
				Per. ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per. ct.*								
	1917.																
32	Aug. 28	B.	Fair	27.53	10.56	2.2	2.4	1.92	0.31			Odor strong; appearance good; color normal; temperature, 0° C.					
		D.	Strong	27.63	10.78	2.3	2.2		.30								
		E.	Good	28.15	10.65	2.0	2.2	1.72	.30								
		H.	do	27.48	10.52			1.81					4,100,000	4,000,000	1,000,000	0	100
		S.								0	0		4,100,000	3,500,000	1,000,000	0	100
			Average.	27.70	10.63	2.2	2.2	1.82	.30	0	0		4,100,000	3,800,000	1,000,000	0	100
48	Aug. 31	B.	Fair	27.86	10.65	2.8	2.1	1.82	.32			Odor strong; melted 1					
		D.	Good	27.69	11.33	3.0	3.3	2.12	.30								
		H.	do	27.91	10.96	2.7	3.0		.30	0	0						
		S.	do	27.67	10.49	3.2	2.6	1.91	.31	0	0						
			Average.	27.78	10.86	2.9	2.8	1.95	.31	0	0						
66	Sept. 5	D.	Fair	26.91		3.3	[2] 3.9	1.66	.27			Odor sour; appearance good; color normal; temperature,—2° C.					
		E.	Good	26.65	9.85	3.0	2.7	2.16	.30								
		H.	do	26.47	9.78	2.9	1.8	2.05		0	0		113,000,000	66,000,000	8,500,000	2,200,000	1,000,000
		S.	do	26.70	9.73	3.1	3.0	1.84	.33	0	0		98,000,000	40,000,000	7,500,000	2,200,000	1,000,000
			Average3	26.68	9.79	3.1	2.5	1.93	.30	0	0		105,500,000	53,000,000	8,000,000	2,200,000	1,000,000
72	Sept. 6	B.	Fair	28.87	11.56	2.7	3.1	2.06	.31			Odor strong; appearance good; color normal; temperature, —1° C.					
		D.	Bad							0	0						

E.	Good	29.05	11.71	2.5	2.7	1.82	.32	......	......	......	......	......	......	......	......
H.	do	28.47	11.50	2.8	[2] 4.5	1.74	.29	......	......	......	30,000,000	6,000,000	900,000	2,600,000	100,000
S.	do	28.59	11.71	2.8	2.7	2.01	.33	......	......	......	36,000,000	6,000,000	850,000	2,000,000	100,000
	Average [3]	28.75	11.62	2.7	2.8	1.91	.31	0	0	......	33,000,000	6,000,000	900,000	2,300,000	100,000
Grand average [3]		27.73	10.73	2.7	2.7	1.90	.31	0	0	......	47,500,000	20,900,000	3,300,000	2,300,000	370,000
Maximum [3]		28.75	11.62	3.1	2.8	1.95	31	0	0	......	105,500,000	53,000,000	8,000,000	2,300,000	1,000,000
Minimum [3]		26.68	9.79	2.2	2.2	1.82	.30	0	0	......	4,100,000	3,800,000	900,000	2,200,000	1,000

[1] Partially melted when received. [2] Cloudy solution interfered with nesslerization. [3] Abormal figures omitted.

Formula values: Sample 32= −6.38; sample 48= +0.47+; sample 66= +27.91; sample 72= +3.10.

TABLE 18.—*Results of examination of frozen commercial second-grade whole egg containing no sugar or salt (grading observed in some; material considered by manufacturers to be too good for tanners' grade).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.			Distribution.					Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
	1917.				1917.	1917.	°F.	°F.			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Lbs.		Hrs.		°F.
14	Aug. 6	J.	Cracks from Fort Dodge, Iowa.	Cracks[1]	Aug. 2	Aug. 6	35	63	16	......	.....	.....	.....	.....	.....	25	Small hand churn.	3	Strong...	+1
22	Aug. 8	R.	Current receipts from Jacksonville, Ill.	Current receipts[2]	Aug. 4	Aug. 8	37	74	4	849	24	71	0	24	5	20	Small power churn	2½	Good.....	−5
41	Aug. 10	J. R.	Cracks from June case pack and current receipts from Mount Vernon, Ill.	Cracks and current receipts.[3]	Aug. 4 and 6	Aug. 4 and 6	36	62	2	1,258	5	90	2	5	3	9½	In sample can with sterile milk stirrer.	4	....	−7
51	...do....	J.	.....do	.....do.[4]	...do....	...do....	36	62	5	......	.....	.....	.....	.....	.....	9¾	.....do	½	Like tanners.	−7
52	Aug. 4 and 9	R.	Unknown	Unknown[5]	......	......	....	....	....	......	.....	.....	.....	.....	.....	25	....	....	....	....
53	May 8	H.	.....do	.....do.[6]	......	......	....	....	....	......	.....	.....	.....	.....	.....	30	....	....	....	....

[1] Graded commercially. Included good, 32 per cent; light green whites, 21 per cent; very weak, 20 per cent; light sour, 13 per cent; mottled yolks, 5 per cent; advanced hatch spots, 4 per cent; mixed rots (mostly mottled), 4 per cent; embryo, 1 per cent.

[2] Graded out from samples 20 and 21. Included advanced hatch spots and small blood rings, 19 per cent; mottled yolks, 17 per cent; light sour, 14 per cent; cloudy white, 14 per cent; partly addled, 14 per cent; weak, 13 per cent; good, 3 per cent; slightly stuck yolks, 3 per cent; duck, 2 per cent; light green whites, 1 per cent.

[3] Graded out from samples 40, 42, 43, and 44. Included very weak, 35 per cent; advanced hatch spots with mottled yolks, 19 per cent; mottled and bloated yolks, 17 per cent; frozen, 17 per cent; olive-colored yolks, 3 per cent; good, 3 per cent; slightly stuck yolks, 2 per cent; blood rings, 2 per cent; sour, 2 per cent.

[4] Graded out from sample 50. Included frozen, very weak, small blood rings, very mottled yolks, slightly sour, slightly stuck yolks.

[5] Prepared before investigators arrived, therefore unbiased commercial grading.

[6] Commercially packed in May. Purchased in August.

Sample No.	Date analyzed.	Initial of analyst.	Odor when anayzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram.				
						Titration.	Nesslerization.						Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, 37° C., 48 hours.	Alkali producers, 37° C., 48 hours.	Confirmed *B. coli.*
				Per ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
14	1917. Aug. 25	B.	Sour.....	27.32	10.75	4.0	4.8	1.64	0.25	......	......	Odor sour; appearance good; color normal; temp. −2° C.	205,000,000	51,000,000	......	......	1,000,000
		D.	...do.....	27.66	11.22	4.2	5.1	......	.26	......	......						
		E.	...do.....	......	......	......	......	......	......	0	0	......	......	......	......	......	......
		H.	...do.....	28.21	11.12	3.7	2.4	1.88	.26	......	......	......	......	......	......	......	......
		S.	...do.....	27.45	11.09	......	3.5	1.87	.24	......	......	......	217,000,000	65,000,000	......	......	1,000,000
			Average.	27.66	11.05	4.0	4.0	1.80	.25	0	0	......	211,000,000	58,000,000	......	......	1,000,000
22	Aug 28	B.	Good....	27.86	11.27	3.2	2.9	2.29	.29	0	0	Few blood clots; odor strong; appearance good; color normal; temp. 0° C.	1,400,000	7,100,000	2,400,000	96,000	100,000
		D.	Sour.....	27.89	11.21	3.0	3.1	2.34	.28	0	0						
		E.	Strong...	27.71	10.82	2.7	2.6	1.68	.29	......	......						
		H.	Good....	27.68	11.10	......	2.3	1.71	......	......	......	......	2,200,000	8,300,000	2,800,000	103,000	100,000
			Average.	27.79	11.10	3.0	2.7	2.01	.29	0	0	......	1,800,000	7,700,000	2,600,000	100,000	100,000
41	Aug. 30	B.	Strong...	26.85	10.06	3.0	3.0	......	.32	0	0	......	......	......	......	......	......
		E.	Good....	27.10	10.09	2.3	2.6	1.66	.32	0	0	......	......	......	......	......	......
		H.	...do.....	27.31	10.22	2.5	1.9	1.79	......	......	......	No embryos or molds; few blood clots and blood rings; odor good; appearance good; temp. 0° C.	340,000	600,000	100,000	0	100,000
		S.	...do.....	27.27	10.33	2.5	2.0	1.70	.31	......	......		410,000	900,000	100,000	0	100,000
			Average.	27.13	10.18	2.6	2.4	1.72	.32	0	0	......	380,000	800,000	100,000	0	100,000

TABLE 18.—*Results of examination of frozen commercial second-grade whole egg containing no sugar or salt, etc.*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli*.
				Per ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
51	1917. Aug. 31	B.	Strong	29.03	11.81	4.5	4.6	1.89	0.28	......	......	Odor bad; appearance good; color normal; temp. +1° C.	180,000,000	6,900,000	3,000,000	320,000	10,000
		D.	Good	29.60	13.25	4.6	4.6	2.21	.25	......	......						
		E.	...do	....	....	....	....	....	....	0	0	....					
		H.	...do	29.63	12.70	4.4	4.7	2.58	.24	......	......	....	177,000,000	3,900,000	2,400,000	280,000	10,000
		S.	...do	29.55	12.01	4.2	3.7	2.19	.30	......	......	....	....	....	....	....	....
			Average	29.45	12.44	4.4	4.4	2.22	.27	0	0	....	178,500,000	5,400,000	2,700,000	300,000	1,0000
52	Sept. 1	B.	Fair	28.38	11.31	3.6	2.4	1.74	.28	......	......	....	....	....	....	....	....
		D.	Strong	28.45	11.38	3.1	3.6	1.74	.27	......	......	Odor strong; appearance good; temp. 0° C.; nothing of significance.	41,000,000	11,100,000	8,400,000	390,000	100,000
		E.	....	27.80	10.76	2.8	2.9	1.96	.27	0	0						
		S.	Good	27.94	10.76	3.2	2.7	1.69	.31	0	0		55,000,000	12,900,000	11,600,000	610,000	100,000
			Average	28.14	11.05	3.2	2.9	1.78	.28	0	0	....	48,000,000	12,000,000	10,000,000	500,000	100,000
53	...do	B.	Fair	30.43	12.82	3.1	2.1	1.66	.30	......	......	Odor strong; appearance good; temp. 0° C.	16,900,000	1,700,000	900,000	100,000	1,000
		D.	Good	30.08	12.43	2.8	3.1	1.79	......	......	......						
		E.	....	....	12.55	2.8	2.7	1.74	.26	0	0	....	....	....	....	....	....
		S.	Good	31.63	13.39	2.8	2.8	1.75	.31	0	0	....	17,800,000	1,500,000	1,300,000	100,000	10,000
			Average	30.71	12.80	2.9	2.7	1.76	.29	0	0	....	17,400,000	1,600,000	1,100,000	100,000	5,500
Grand average				28.38	11.44	3.7	3.2	1.88	.28	0	0	....	76,500,000	14,400,000	3,500,000	200,000	220,000
Maximum				29.45	12.44	4.4	4.4	2.22	.32	0	0	....	211,000,000	58,000,000	10,000,000	500,000	1,000,000
Minimum				27.13	10.18	2.6	2.4	1.72	.25	0	0	....	380,000	800,000	100,000	0	5,500

Formula values: Sample 14= +55.49; sample 22= +2.79; sample 41= −3.38; sample 51= +51.45; sample 52= +11.99; sample 53= −2.04.

TABLE 19.—*Results of examination of frozen experimental tanners' grade whole egg, containing no sugar or salt.*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.								Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
	1917.				1917.	1917.	°*F.*	°*F.*			*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Lbs.*		*Hrs.*		°*F.*
73	Aug. 14	R.	Checks and dirties from Wisconsin.	Checks and dirties[1]	Aug. 13	Aug. 13 and 14	40	62	1	1,265	6	45	37	12	6	6	In sample can with sterile milk stirrer.	4	Bad......	−10

[1] Grading dictated. Graded out from samples 70, 71, and 72. Included mixed rots, 50 per cent; sour, 28 per cent; very cloudy whites, 5 per cent; stuck yolks, 4 per cent; moldy odor, 4 per cent; green yolks, 4 per cent; unclassified, 3 per cent; very dark yolks, 1 per cent; very stale, 1 per cent.

TABLE 19.—*Results of examination of frozen experimental tanners' grade whole egg, containing no sugar or salt*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram.				
						Titration.	Nesslerization.						Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, 37° C., 48 hours.	Alkali producers, 37° C., 48 hours.	Confirmed *B. coli*.
				Per ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
73	1917. Sept. 6	D.	Bad	....	....	....	....	....	....	+	+	Odor bad; appearance good; color normal; temperature −1° C.	....	....	....	....	....
		E.	Good	28.41	11.12	2.7	3.3	1.94	0.22	......	......	....					
		H.	...do	27.01	10.21	3.2	2.0	1.88	.24	......	......	....	18,700,000	5,000,000	2,000,000	230,000	100,000
		S.	...do	27.34	10.59	3.1	3.0	1.86	.28	......	......	....	13,800,000	3,000,000	2,000,000	170,000	100,000
			Average	27.59	10.64	3.0	2.8	1.89	.25	+	+	....	16,300,000	4,000,000	2,000,000	200,000	100,000

Formula value: Sample 73= +11.28.

TABLE 20.—*Results of examination of frozen commercial tanners' grade whole egg containing no sugar or salt.*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.				Eggs in breaking room.									Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
	1917.				1917.	1917.	° F.	° F.							P. ct.	Lbs.		Hrs.		° F.
16	Aug. 7	H.	Current receipts from Oklahoma.	Current receipts.[1]	July 27	Aug. 7	35	63	16	43,000	.....	.....	.....	.....	1	27	In sample can with sterile breaking knife.	4	Bad.....	+1
77	Aug. 14	H.	Checks and dirties from Wisconsin.	Checks and dirties.[2]	Aug. 13	Aug. 13 and 14	40	62	7	12,600	.....	.....	.....	.....	2	27	.....do.....	3	...do.....	−1

[1] Commercial grading. Said to be sold to a manufacturer of tanners' yolks.
[2] Commercial grading. As manufacturer did not expect Bureau representatives to take a sample of this product, grading was unbiased. Said to be used up in fertilizer works.

TABLE 20.—*Results of examination of frozen commercial tanners' grade whole egg containing no sugar or salt*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram.				
						Titration.	Nesslerization.						Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, 37° C., 48 hours.	Alkali producers, 37° C., 48 hours.	Confirmed *B. coli.*
	1917.			*Per ct.*	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
16	Aug. 22	B.	Putrid	27.66	10.72	6.6	8.6	2.15	0.21			1 embryo; 1 blood ring; no mold; odor sour and slightly putrid; appearance good; color normal; temperature 0° C.	264,000,000	104,000,000			10,000,000
		D.	Sour	27.13	10.46	6.7	5.7	2.18	.23								
		E.	...do	27.19	10.52	6.2	6.0	2.08	.23	0	+						
		H.	...do	27.43	10.44		5.9	2.33	.19	0	+						
		S.	Bad	27.37	10.52	5.9	5.8	2.17	.18	0	+		133,000,000	98,000,000			10,000,000
			Average.	27.36	10.53	6.4	6.4	2.18	.21	0	+		198,500,000	101,000,000			10,000,000
77	Sept. 5	B.								+	0	Blood rings; shells, dirt; odor bad; appearance good; color normal; temperature −2° C.	340,000,000	221,000,000	26,600,000	77,000,000	10,000,000
		D.	Sour	27.20	10.85	6.7	9.4[1]	2.29	0.21								
		E.	...do	27.19	10.21	7.5	7.0										
		H.	...do	26.55	9.95	6.6	8.0	2.25	.20								
		S.	Putrid	26.09	9.77	8.1	8.2	2.34	.22				380,000,000	191,000,000	29,400,000	89,000,000	10,000,000
			Average[2].	26.76	10.20	7.2	7.7	2.29	.21	+	0		360,000,000	211,000,000	28,000,000	83,000,000	10,000,000
Grand average[2]				27.09	10.38	6.8	6.9	2.24	.21	+	+		279,300,000	156,000,000	28,000,000	83,000,000	10,000,000
Maximum[2]				27.36	10.53	7.2	7.7	2.29	.21	+	+		360,000,000	211,000,000	28,000,000	83,000,000	10,000,000
Minimum[2]				26.76	10.20	6.4	6.4	2.18	.21	0	0		198,500,000	101,000,000	28,000,000	83,000,000	10,000,000

[1] Cloudy solution interfered with nesslerization.

[2] Abnormal figure omitted.

Formula values: Sample 16= + 105.74; sample 77= +148.04.

TABLE 21.—*Results of examination of frozen commercial drip containing no sugar or salt.*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell. Previous history.	Eggs in shell. Kind of eggs.	Eggs in shell. Date received.	Eggs in shell. Date candled.	Temperature of holding room.	Eggs in breaking room. Temperature of breaking room.	Eggs in breaking room. Number of breakers.	Eggs in breaking room. Number of eggs graded.	Distribution. Used in sample.	Distribution. As first grade.	Distribution. As soft grade.	Distribution. As second grade.	Distribution. As tanner grade.	Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
							°F.	°F.			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Lbs.		Hrs.		°F.
15	1917. Aug. 7	H.	Current receipts from Oklahoma.	Current receipts [1].	1917. July 27	1917. Aug. 7	35	63	16	......	......	......	......	......	......	24	In sample can with sterile breaking knife.	4	Strong...	+1

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli*.
				Per ct.	Per ct.	Mg. per 100 grams.	Mg. per 100 grams.	Cc. per gram.	Per ct.								
15	1917. Aug 23	E.	Sour.....	19.53	5.37	2.4	3.3	1.84	0.32	0	0	Blood rings; no molds; no embryos; odor strong; appearance good; color light; temperature −2° C.	65,000,000	21,800,000	....	....	1,000,000
		H.	Strong...	20.19	5.59	2.6	2.9	1.90	.37	0	0						
		S.	Good....	21.59	5.90	2.8	3.2	1.94	.36	0	0	....	62,000,000	19,200,000	....	....	1,000,000
			Average.	20.44	5.62	2.6	3.1	1.89	.35	0	0	....	63,500,000	20,500,000	....	....	1,000,000

[1] Included all drip collected from breaking knives and trays. Proportion of white was high.

Formula value: Sample 15= +23.25.

TABLE 22.—*Results of examination of frozen whole egg prepared from inedible eggs under experimental conditions (containing no sugar or salt).*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell. Previous history.	Kind of eggs.	Date received.	Date candled.	Eggs in breaking room. Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution. Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.	Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
							°F.	°F.			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Lbs.		Hrs.		°F.
23	1917. Aug. 8	J.	Current receipts from Jacksonville, Ill.	Partially addled (mixed rots).[1]	1917. Aug. 4	1917. Aug. 8	37	74	1	......	......	......	......	......	......	26	In sample can with sterile breaking knife.	2	Good.....	−5
24	...do....	J.	.....do.....	Slightly stuck yolks.[2]	...do....	...do....	37	74	1	......	......	......	......	......	......	10	.....do.....	1½	...do.....	−5
25	...do....	J.	.....do.....	Slightly disintegrated yolks (border-line rots).[3]	...do....	...do....	37	74	1	......	......	......	......	......	......	20	.....do.....	2	...do.....	−5
27	Aug. 8 and 9	J.	.....do.....	Completely addled (white rots).[4]	...do....	Aug. 8 and 9	37	74	1	......	......	......	......	......	......	15	.....do.....	1½	Offensive	−5
28	Aug. 9	J.	.....do.....	Heavily stuck yolks (may be moldy).[5]	...do....	...do....	37	74	1	......	......	......	......	......	......	26	.....do.....	2	Moldy...	−5
68	Aug. 13 and 14	H.	Checks and dirties from Iowa.	Sour[6].....	Aug. 11	Aug. 13	40	66	10	......	......	......	......	......	......	6½	In sample can with sterile milk stirrer.	9	Sour.....	−10
69	...do....	H.	.....do.....	Green white[7].....	...do....	...do....	40	66	10	......	......	......	......	......	......	5½	.....do.....	9	Slightly sour.	−10
75	Aug. 14	J.	Cracks from Davenport, Iowa.	Cracks with moldy shells.[8]	Aug. 10	...do....	40	62	1	......	......	......	......	......	......	30	.....do.....	1	Slightly moldy.	−10

[1] Obtained from candling room rejects. Cups changed after inferior eggs. Consisted of deteriorated broken yolks partially mingled with whites and containing whitish areas.
[2] From candling room rejects. Cups changed after inferior eggs. Had clear whites and yolks attached by small area. Fairly good appearance.
[3] From candling room rejects. Cups changed after inferior eggs. Consisted of spreading yolks, cloudy whites, and mottled yolks.
[4] From candling room rejects. No putrid eggs used. Whites and yolks mingled. Many whitish streaks. Appearance very repulsive.
[5] From candling room rejects. Most showed dark areas before candle. No moldy addled eggs included.
[6] Graded out from regular straight break. Two pounds collected on Aug. 13 in 5 hours and frozen; 4½ pounds added on Aug. 14 in 4 hours. Churned and frozen.
[7] Graded out from regular straight break. One and three-quarter pounds collected on Aug. 13 in 5 hours and frozen; 3¾ pounds added on Aug. 14 in 4 hours. Churned and frozen.
[8] No stuck yolks, green whites, or sours included.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli*.
				Per ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
23	1917. Aug. 27	B.	Fair	28.65	11.42	4.5	4.2	1.99	0.25	0	0	Odor strong; melted.[1]					
		D.	Strong	28.63	11.41	......	4 9	2.32	.24	0	0						
		E.	Fair	28.01	11.34	4.1	3.6	2.28	.24	......	......						
		H.	Good	28.04	11.49	4.9	4.7	1.81	.25	......	......						
		S.	...do	28.60	11.32	4.4	3.8	2.37	.23	......	......						
			Average	28.39	11.40	4.5	4.2	2.15	.24	0	0						
24	...do	B.	Eggy	27.89	10.80	2.9	2.8	1.88	.30	0	0	Odor very strong; melted.[2]					
		D.	Strong	28.14	10.92	2.7	4.0	2.22	......	0	0						
		E.	Fair	27.90	10.89	......	2.5	2.19	.29	......	......						
		H.	Good	27.84	11.01	2.6	2.6	1.93	.27	......	......						
		S.	...do	27.55	10.55	2.9	2.9	2.11	.28	......	......						
			Average	27.86	10.83	2.8	3.0	2.07	.29	0	0						
25	...do	B.	Fair	28.27	10.97	3.3	3.1	1.93	......	......	......	Odor sour; melted.[1]					
		D.	Strong	27.63	......	3.3	3.4	......	.26	......	......						
		E.	Fair	28.14	11.29	3.1	2.7	2.31	.31	0	0						
		H.	Good	27.83	11.32	2.6	2.7	•1.82	.28	0	0						
		S.	...do	26.69	10.44	3.4	2.9	1.99	.31	......	......						
			Average	27.71	11.01	3.1	3.0	2.01	.29	0	0						
27	...do	B.	Moldy	27.98	11.28	13.2	11.2	3.26	.09	......	......	Odor sour; melted.[2]					
		D.	Sour	28.37	11.36	12.6	13.3	3.68	.13	......	......						
		E.	Sour and putrid.	28.19	11.41	12.8	11.6	3.63	.13	0	+						
		H.	Bad	28.07	11.63	13.0	9.8	3.15	.13	0	+						
		S.	Moldy	29.11	11.22	12.6	13.3	3.59	.11	......	......	Blood ring; blood clots; shells.					
			Average	28.34	11.38	12.8	11.8	3.46	.12	0	+						

[1] Partially melted when received.

[2] Completely melted when received.

TABLE 22.—*Results of examination of frozen whole egg prepared from inedible eggs under experimental conditions (containing no sugar or salt)*—Con.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis).		Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram.				
						Titration.	Nesslerization.						Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, 37° C., 48 hours.	Alkali producers, 37° C., 48 hours.	Confirmed *B. coli.*
	1917.			*Per ct.*	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
28	Aug. 27.	B.	Sour	27.98	10.93	13.1	10.9	6.76	0.04	......	......	Odor sour and slightly putrid; melted.[1]	......	......	......	......	......
		D.	Sour and moldy.	28.05	11.05	12.7	12.2	7.98	.08	......	......	......	......	......	......	......	......
		E.	Very sour	27.88	11.15	12.8	10.0	6.60	.05	......	......	......	......	......	......	......	......
		H.	Bad	28.25	11.43	12.3	7.8	5.56	.04	......	......	......	......	......	......	......	......
		S.	Sour	27.75	11.06	13.3	11.4	6.17	.04	+	0	......	......	......	......	......	......
			Average	28.38	11.12	12.8	10.5	6.61	.05	+	0	......	......	......	......	......	......
68	Sept. 6	B.	Sour	27.50	10.59	......	5.8	2.21	.18	0	0	Odor sour; appearance good; color normal; temp. −1° C.	......	......	......	......	......
		E	...do	27.78	10.62	4.2	6.5	2.07	.19	0	0						
		H.	Bad	28.44	10.80	4.9	3.7	......	.16	0	0	......	399,000,000	378,000,000	24,700,000	138,000,000	10,000,000
		S.	Putrid	27.45	10.55	4.5	5.5	2.28	.22	......	......	......	395,000,000	362,000,000	23,300,000	132,000,000	10,000,000
			Average	27.79	10.64	4.5	5.4	2.19	.19	0	0	......	397,000,000	370,000,000	24,000,000	135,000,000	10,000,000
69	...do	B.	Strong	27.15	9.83	5.4	5.8	......	.18	0	0	Odor sour; appearance good; color normal; temp. −1° C.	......	......	......	......	......
		E.	Good	27.62	10.07	4.4	6.5	1.82	.16	0	0						
		H.	...do	26.99	10.15	5.0	4.5	1.94	.18	......	......	......	249,000,000	197,000,000	33,000,000	38,000,000	10,000,000
		S.	Strong	27.21	10.01	4.7	5.7	1.85	.20	......	......	......	321,000,000	230,000,000	37,000,000	42,000,000	10,000,000
			Average	27.24	10.02	4.9	5.6	1.87	.18	0	0	......	285,000,000	213,500,000	35,000,000	40,000,000	10,000,000
75	Sept. 4	B.	Good	27.53	10.69	2.2	1.8	......	......	......	......	No mold; 1 green spot with filaments; odor moldy; appearance good; color normal; temp. −2 °C.	......	......	......	......	......
		D.	Moldy	27.50	10.58	2.8	2.1	1.83	.24	......	......		4,300,000	900,000	90,000	0	10,000

		E.	Good.....	27.53	10.58	2.3	2.1	1.88	.30	......	......	......	......	......	......	......	......
		H.	...do......	26.15	10.74	2.2	2.3	1.91	.28	......	......	......	......	......	......	......	......
		S.	....	......	......	......	......	......	......	+	0	......	4,600,000	900,000	110,000	0	10,000
			Average..	27.18	10.65	2.4	2.1	1.87	.27	+	0	......	4,500,000	900,000	100,000	0	10,000

[1] Partially melted when received.

Formula values: Sample 23= +19.02+; sample 24= +1.14+; sample 25= +3.41+; sample 27= +123.18+; sample 28= +156.77+; sample 68= +121.57; sample 69= +101.49; sample 75= +2.32.

TABLE 23.—*Results of examination of frozen experimental whole egg containing no sugar or salt, to show progressive decomposition.*

Sample No.	Date prepared.	Initial of investigator.	Eggs in shell.					Eggs in breaking room.								Size of sample.	How churned.	Time consumed in preparing sample.	Odor when put in freezer.	Temperature of freezer.
			Previous history.	Kind of eggs.	Date received.	Date candled.	Temperature of holding room.	Temperature of breaking room.	Number of breakers.	Number of eggs graded.	Distribution.									
											Used in sample.	As first grade.	As soft grade.	As second grade.	As tanner grade.					
							°F.	°F.								Lbs.		Hrs.		°F.
60	1917. Aug. 13	H.	Checks and dirties from Iowa.	Checks and dirties[1]	1917. Aug. 8, 11	1917. Aug. 11, 13	40	66	10	......	......	......	......	......	......	15	In large power churn.	1	Good.....	−10
61	...do.....	H.	.....do..........	.....do.[2].........	...do.....	...do.....	40	66	10	......	......	......	......	......	......	15	.....do..........	1	Strong...	−10
62	...do.....	H.	.....do..........	.....do.[3].........	...do.....	...do.....	40	66	10	......	......	......	......	......	......	15	.....do..........	1	Slightly sour.	−10
63	...do.....	H.	.....do..........	.....do.[4].........	...do.....	...do.....	40	66	10	......	......	......	......	......	......	15	.....do..........	1	Sour and putrid.	−10

[1] Commercially graded; sample placed in freezer immediately.
[2] From same churnful as sample 60; sample held at 66° for 6 hours before placing in freezer.
[3] From same churnful as sample 60; sample held at 66° for 23 hours before placing in freezer.
[4] From same churnful as sample 60; sample held at 66° for 29½ hours before placing in freezer.

TABLE 23.—*Results of examination of frozen experimental whole egg containing no sugar or salt, to show progressive decomposition*—Continued.

Sample No.	Date analyzed.	Initial of analyst.	Odor when analyzed.	Total solids (wet basis).	Ether extract (wet basis).	Ammonia nitrogen (wet basis). Titration.	Ammonia nitrogen (wet basis). Nesslerization.	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol.	Skatol.	Physical examination.	Organisms per gram. Plain agar, 20° C., 120 hours.	Organisms per gram. Plain agar, 37° C., 48 hours.	Organisms per gram. Acid producers, 37° C., 48 hours.	Organisms per gram. Alkali producers, 37° C., 48 hours.	Organisms per gram. Confirmed *B. coli.*
				Per ct.	*Per ct.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*								
60	1917. Sept. 4	B.	Good....	28.95	11.78	2.5	2.3	1.82	0.32	0	0	Odor good; appearance good; color normal; temp., −2° C.					
		D.	...do.....	29.30	11.92	3.0	3.1	1.78	....	0	0		....	....	....	....	....
		E.	...do.....	28.84	11.96	2.6	2.3	1.89	.31	.....	.....	....	3,000,000	1,500,000	600,000	50,000	100,000
		H.	...do.....	28.56	11.46	3.0	2.6	....	.29	.....	.....	....	2,600,000	1,800,000	600,000	50,000	10,000
			Average.	28.91	11.78	2.8	2.6	1.83	.31	0	0	....	2,800,000	1,700,000	600,000	50,000	55,000
61	...do.....	B.	Fair.....	28.74	11.65	2.7	3.2	1.75	.32	0	0	Odor strong; appearance good; color normal; temp., −2° C.	4,400,000	3,000,000	900,000	78,000	10,000
		D.	Strong...	29.34	11.88	2.8	2.9	1.72	....	0	0						
		E.	Good....	29.11	11.96	2.6	2.4	2.09	.29	.....	.....	....	4,100,000	2,500,000	650,000	82,000	10,000
		H.	...do.....	28.87	11.77	3.0	3.0	2.07	.29	.....	.....	....					
			Average.	29.02	11.82	2.8	2.9	1.91	.30	0	0	....	4,300,000	2,800,000	800,000	80,000	10,000
62	...do.....	B.	Sour.....	28.38	11.60	6.5	[1] 3.5	2.25	.04	.....	.....	Odor sour; appearance good; color normal; temp., −2° C.	287,000,000	296,000,000	287,000,000	12,700,000	10,000,000
		D.	...do.....	28.91	11.81	6.9	6.3	2.18	.00	.....	.....						
		E.	...do.....	28.28	11.53	6.5	6.1	2.36	.04	0	0	....	282,000,000	291,000,000	273,000,000	11,300,000	10,000,000
		H.	Bad.....	28.79	11.85	6.8	6.5	2.36	.01	0	0	....					
			Average [2]	28.59	11.70	6.7	6.3	2.29	.02	0	0	....	284,500,000	293,500,000	280,000,000	12,000,000	10,000,000
63	...do.....	B.	Sour.....	27.99	11.28	8.3	[1] 5.9	2.20	.00	0	0	Odor bad; appearance good; color normal; temp., −2° C.	282,000,000	246,000,000	144,000,000	11,700,000	1,000,000
		D.	...do.....	28.81	11.70	7.6	9.9	2.21	.00	.....	.....						
		E.	...do.....	27.81	11.23	8.0	7.0	2.34	.00	0	0	....	218,000,000	230,000,000	137,000,000	10,400,000	1,000,000
		H.	Bad.....	27.96	11.31	8.7	7.8	2.33	.00	0	0	....					
			Average [2]	28.14	11.38	8.2	8.2	2.27	.00	0	0	....	250,000,000	238,000,000	140,500,000	11,100,000	1,000,000

[1] Lost by spattering. [2] Abnormal figure omitted.

Formula values: Sample 60= −3.17; sample 61= −2.05; sample 62= +126.05; sample 63= +115.43.

DISCUSSION OF RESULTS OF EXAMINATION.

The following conclusions may be drawn from Tables 8 to 23.

1. Using the methods of examination as modified during this investigation and fully described on pages 85 to 96, several analysts when examining the same samples at the same time obtained results which agree closely. This is important, as it proves that the methods are reliable and with justice to producer and consumer alike may be depended upon as the basis for judgment concerning the degree of decomposition which has taken place.

2. The differences shown by the analytical results parallel to a remarkable degree the results of physical examination as determined in advance by examination of the individual eggs comprising the samples. It is therefore evident that from an analysis of a frozen egg product an accurate decision may be reached concerning the character of the raw materials used in its preparation.

3. In the samples of experimental first-grade whole egg (Table 8) the very close agreement in the results obtained from different samples for ammonia nitrogen, acidity of fat, and reducing sugar should be noted in connection with the fact that the raw materials used came from three different States. In the seven samples of this product the average ammonia nitrogen figures were respectively 1.9, 2.1, 2.2, 2.1, 2.4, 2.2, and 2.3 milligrams per 100 grams; the average acidity of fat figures were 1.84, 1.87, 1.92, 1.89, 1.85, 1.86, and 1.86 cubic centimeters of N/20 sodium ethylate required per gram; and the average reducing sugar figures were 0.30, 0.30, 0.29, 0.31, 0.30, 0.27, and 0.29 per cent. The comparatively low figures found for ammonia nitrogen and for acidity of fat, and the high figures for reducing sugar in the case of these eggs packed in August, when eggs are admittedly of the poorest quality, are also worthy of note, and prove conclusively that eggs showing practically no decomposition occur in ordinary breaking stock, even in August. The proper inference is that the degree to which such eggs are present is proportional to the care with which the eggs while still in the shell have been gathered, cooled, and handled. An index to the amount of care in handling used in August, 1917, is furnished by the fact that in sample 64 only 57 per cent of the eggs graded could be placed in first-grade frozen whole egg, and in sample 70 only 45 per cent could be so used. The fact that in these two samples it was necessary to place 26 and 37 per cent, respectively, in the soft grade indicates clearly that the raw material became too greatly heated during transportation or storage. This is further emphasized from another point of view by the fact that sample 46, prepared principally from cracks from June case packs which had been held subsequently in cold storage for two months, showed ammonia nitrogen to the extent of 2.1 milligrams per 100 grams, acidity of fat of 1.89

cubic centimeters of N/20 sodium ethylate required per gram, and reducing sugar of 0.31 per cent.

4. The figures obtained from the products prepared experimentally by the investigators cited showed somewhat less decomposition than the figures obtained from products prepared commercially from the the same raw materials (Table 9). In the six samples of the latter product, the average ammonia nitrogen figures were, respectively, 2.3, 2.5, 2.3, 2.8, 2.5, and 2.6 milligrams per 100 grams; the average acidity of fat figures were 1.95, 1.83, 1.77, 1.77, 1.73, and 1.76 cubic centimeters of N/20 sodium ethylate required per gram; and the average reducing sugar figures were 0.31, 0.30, 0.32, 0.29, 0.30, and 0.32 per cent. This is readily explained by the fact that in the three samples in which a record of distribution was kept, it was found that 92, 89, and 94 per cent of the eggs graded were placed in the first-grade products by the commercial graders, as compared with 57 and 45 per cent as graded by the investigators.

5. The bacterial contents of the first-grade experimentally prepared and first-grade commercially prepared samples were very similar, as was the distribution of the bacteria into groups in both types of sample. In the experimentally prepared samples the total bacterial counts averaged 4,000,000 per gram, with a maximum of 10,500,000 and a minimum of 120,000, while in the commercially prepared samples the corresponding figures were 2,600,000, 5,300,000, and 160,000.

6. In close agreement with the figures already cited are those obtained from commercially prepared first-grade whole egg containing sugar and salt (Table 10). In the five samples of this product, one of which was prepared in April and the other four in August, the average ammonia nitrogen figures were 1.8, 2.4, 2.5, 2.3, and 2.4 milligrams per 100 grams; the average acidity of fat figures were 1.68, 1.69, 1.90, 1.80, and 1.67 cubic centimeters of N/20 sodium ethylate required per gram; and the average reducing sugar figures were 0.30, 0.28, 0.31, 0.29, and 0.30 per cent. In these samples the total bacterial counts averaged 340,000, 15,000,000, 7,800,000, 2,900,000, and 6,300,000 per gram.

7. Although an attempt was made to separate edible breaking stock eggs into two portions, one (first grade) to be of higher quality than the other (soft grade), a comparison of the results already cited for first-grade whole egg with those obtained from experimentally prepared soft-grade (Table 11) and commercially prepared soft-grade (Table 12) whole egg indicates very strongly that such grading is impracticable with breaking stock eggs. In the four samples of experimentally prepared soft-grade whole egg, the average ammonia nitrogen figures were 2.3, 2.2, 2.5, and 2.4 milligrams per 100 grams; the average acidity of fat figures were 1.82, 1.84, 1.84, and 1.82 cubic

centimeters of N/20 sodium ethylate required per gram; the average reducing sugar figures were 0.29, 0.28, 0.32, and 0.30 per cent; and the average total bacterial count was 3,600,000 per gram, with a maximum of 9,300,000 and a minimum of 320,000. In the three samples of commercially prepared soft-grade whole egg, two of which were prepared in August and one in April, the average ammonia nitrogen figures were 2.4, 2.4, and 2.0, milligrams per 100 grams; the average acidity of fat figures were 1.84, 1.99, and 1.73 cubic centimeters of N/20 sodium ethylate required per gram; the average reducing sugar figures were 0.27, 0.33, and 0.32 per cent; and the average total bacterial count was 1,600,000 per gram, with a maximum of 3,800,000 and a minimum of 130,000.

8. As it is the practice in some breaking plants to have the "leakers" broken out by the candlers in the semidarkness of the candling room where proper grading is impossible, the products referred to in Table 13 were prepared under varying conditions. The results are clearly in favor of the leakers opened in the breaking room.

9. The results in Table 14 were obtained from experimentally prepared first-grade yolk of the same general quality as the samples of whole egg reported in Table 8. In the two samples prepared and examined, the average ammonia nitrogen figures were 4.1 and 4.4 milligrams per 100 grams; the average acidity of fat figures were 1.81 and 1.80 cubic centimeters of N/20 sodium ethylate required per gram; the average reducing sugar figures were 0.20 and 0.18 per cent; and the average total bacterial counts were 240,000 and 280,000 per gram.

10. Indistinguishable from the samples just discussed, even though showing somewhat higher bacterial counts, were the samples of commercially prepared first-grade yolk (Table 15). In the four samples of the latter product the average ammonia nitrogen contents were 4.2, 4.2, 4.0, and 4.2 milligrams per 100 grams; the average acidity of fat figures were 1.97, 1.85, 1.99, and 1.84 cubic centimeters of N/20 sodium ethylate required per gram; the average reducing sugar results were 0.20, 0.19, 0.17, and 0.17 per cent; and the average total bacterial counts were 5,300,000, 270,000, 3,000,000, and 1,600,000 per gram. Because only eggs with fairly firm yolks can be separated commercially, the proportion of the eggs graded commercially into the first-grade yolk in the two samples in which a distribution record was kept was decidedly lower than in the case of commercially prepared whole egg. This explains why the experimental yolk and commercial yolk gave analytical results which agreed much more closely than in the case of the experimentally and commercially prepared whole egg. In the two samples mentioned, 77.0 per cent and 71.0 per cent of the eggs graded were placed in the samples.

11. The commercially prepared first-grade yolk containing sugar (Table 16) yielded results in close agreement with the unsugared yolk of similar grade.

12. Up to this point the tables have dealt with samples which were considered fit for food by the representatives of the Bureau. From now on they deal with samples considered inedible or of questionable quality. Not all of the eggs which entered the samples described in Tables 17 and 18 were inedible. In fact, many edible eggs were used in these products, but the proportion of inedible eggs used was large enough to warrant considering the resulting mixtures inedible.

13. In the samples of experimental second-grade egg reported in Table 17, the comparatively high ammonia nitrogen figures of 2.9, 3.1, and 2.7 milligrams per 100 grams in samples 48, 66, and 72, and the very high bacterial counts of 105,500,000 and 33,000,000 per gram in samples 66 and 72 should be noted. It is unfortunate that no bacterial counts could be made in the case of sample 48, for the reason that it was partially melted during transportation from a freezer to the laboratory. The amount of melting was not sufficient, however, to affect the chemical results.

14. In the samples of commercial second-grade egg shown in Table 18, the average figures of 4, 3, 2.6, 4.4, 3.2, and 2.9 milligrams per 100 grams for ammonia nitrogen; of 1.80, 2.01, 1.72, 2.22, 1.78, and 1.76 cubic centimeters of N/20 sodium ethylate required per gram for acidity of fat; of 0.25, 0.29, 0.32, 0.27, 0.28, and 0.29 per cent for reducing sugar; and of 211,000,000, 1,800,000, 380,000, 178,500,000, 48,000,000, and 17,400,000 bacteria per gram indicate clearly the generally unsatisfactory character of the product.

15. Table 19 shows the results of the examination of a sample of experimentally prepared tanners' grade egg which is undoubtedly inedible. In it the average ammonia nitrogen figure was 3 milligrams per 100 grams; the average acidity of fat was 1.89 cubic centimeters of N/20 sodium ethylate required per gram; the average reducing sugar result was 0.25 per cent; indol and skatol, which are indicators of marked decomposition, were present; and the average bacterial count was 16,300,000 per gram. It should be noted that this sample contained 6 per cent of the eggs graded.

16. In strong contrast with the figure of 6 per cent in the experimental tanners' egg are the figures of 1 per cent and 2 per cent of eggs graded out as tanners' egg by the manufacturers (Table 20). The lower proportion of eggs so graded by the manufacturers is clearly reflected in the analytical results of 6.4 and 7.2 milligrams per 100 grams for ammonia nitrogen, of 2.18 and 2.29 cubic centimeters of N/20 sodium ethylate required per gram for acidity of fat, of 0.21 and 0.21 per cent for reducing sugar, of 198,500,000 and 360,000,000 per gram for bacterial counts, and by the presence of indol and skatol.

17. The question of the propriety of saving and freezing the drip from the breaking knives and trays has arisen several times. Giving due consideration to the effect upon the analytical figures of the large proportion of egg white contained in drip, the results of analysis of such material (Table 21) show that it was decomposed to such an extent and had such a high bacterial count that it was unquestionably unfit for food. The average figures were: For total solids, 20.44 per cent; for ether extract, 5.62 per cent; for ammonia nitrogen, 2.6 milligrams per 100 grams; for acidity of fat, 1.89 cubic centimeters of N/20 sodium ethylate required per gram; for reducing sugar, 0.35 per cent; and for bacterial count, 63,500,000 per gram. The odor was strong and sour.

18. The results so far discussed were obtained on samples which contained more than one kind of egg, for the reason that they were made as commercial frozen egg products would normally be made. The proportions of the different types of egg which went into each sample are shown in Tables 8 to 21. Table 22, however, includes a group of samples, each prepared from only one kind of egg, all of which were considered inedible. The table is self-explanatory. Unfortunately, bacteriological examination could not be made of samples 23, 24, 25, 27, and 28 because their delivery from a freezer was so delayed that they became too much melted for the purpose. They were not sufficiently melted, however, to affect the chemical results.

19. In some small breaking plants not provided with "sharp" freezers, with which all breaking plants should be equipped, it is the practice to save the liquid egg all day, transporting it to a freezer at the close of work. Eggs are too perishable a product to be treated in this way, as shown by the fact that when portions of sample 60, which showed 2.8 milligrams per 100 grams for ammonia nitrogen, 1.83 cubic centimeters of N/20 sodium ethylate required per gram for acidity of fat, 0.31 per cent for reducing sugar, and 2,800,000 bacteria per gram, were held for 23 and 29 hours at 66° F. they showed, respectively, 6.7 and 8.2 milligrams per 100 grams for ammonia nitrogen, 2.29 and 2.27 cubic centimeters of N/20 sodium ethylate required per gram for acidity of fat, 0.02 and 0.00 per cent for reducing sugar, and 284,500,000 and 250,000,000 bacteria per gram (Table 23).

20. Tables 8 to 23 clearly indicate that the standard analytical methods evolved during this investigation gave concordant results in the hands of a number of analysts, and that the results thus obtained correspond to the quality of the egg product. It becomes possible, therefore, to express in some concrete form a composite picture of each sample examined.

INTERPRETATION OF RESULTS OF INVESTIGATION.

A series of plots (figs. 1, 2, 3, 4, and 5) was made, with the purpose of finally grouping into a single expression the information obtained.

AMMONIA NITROGEN.

On cross-section paper the amounts of ammonia nitrogen, expressed as milligrams per 100 grams of sample on the wet basis, were plotted as ordinates against the percentages of ether extract as abscissas. The percentages of ether extract as abscissas were chosen not because the ether extract is destroyed by bacterial or enzymatic action in direct proportion as the ammonia increases, but because the normal amount of ammonia was found to be greater in yolk than in whole egg, even when prepared from the freshest eggs obtainable. It is also a known fact that practically all of the ammonia nitrogen occurs in the yolk and that there is no appreciable increase of ammonia nitrogen in the whites of storage eggs or in decaying liquid whites. Therefore any increase in ammonia nitrogen in whole egg is due to decomposition of the yolk, of which the white acts practically as a diluent. Because the ether extract is the best available measure of the amount of yolk present, it was used as the abscissa. Moreover, there is a very great tendency at present to make yolky mixtures, which theoretically may be judged as to quality, as far as ammonia is concerned, if a curve can be drawn, one end of which is determined by the results found for white and the other end for yolk, and which will pass at an intermediate point through the results for whole egg.

The increased amounts of yolky mixture now made are largely due to the demand at present for much more yolk than white. If no preventive steps were taken, white would become a drug on the market. Consequently, in making contracts, especially in the producing section, many breakers demand that the bakers shall take equivalent amounts of yolk and white. As this would provide the bakers with more white than they need if they based orders on their requirements for yolk, they overcome the difficulty by ordering what white they need and then arranging that the equivalent amount of yolk shall be mixed with enough whole egg to give them an amount of yolky mixture equal to the necessary amount of yolk. They can not entirely substitute yolky mixture for yolk, but they can do so to a very large extent, if they are careful not to have so much whole egg in the mixture that their baking recipes are upset. Obviously, in filling one contract, the amount of yolk in the yolky mixtures may be high, while in another it may be low, with the possibility of all degrees of intermediate mixtures. The amount of whole egg in the mixture has been observed to increase as the season advances. To judge such mixtures fairly it has been proposed that the ammonia nitrogen be calculated to a water-free, fat-free, sugar-free basis, instead of to the much simpler wet basis. This would be necessary except for the fact that the same result is accomplished with much less labor by plotting the ammonia nitrogen against the ether extract.

Such a plot of the results in Tables 1 to 23 is presented in figure 1. In it the positions for the results from samples considered edible are

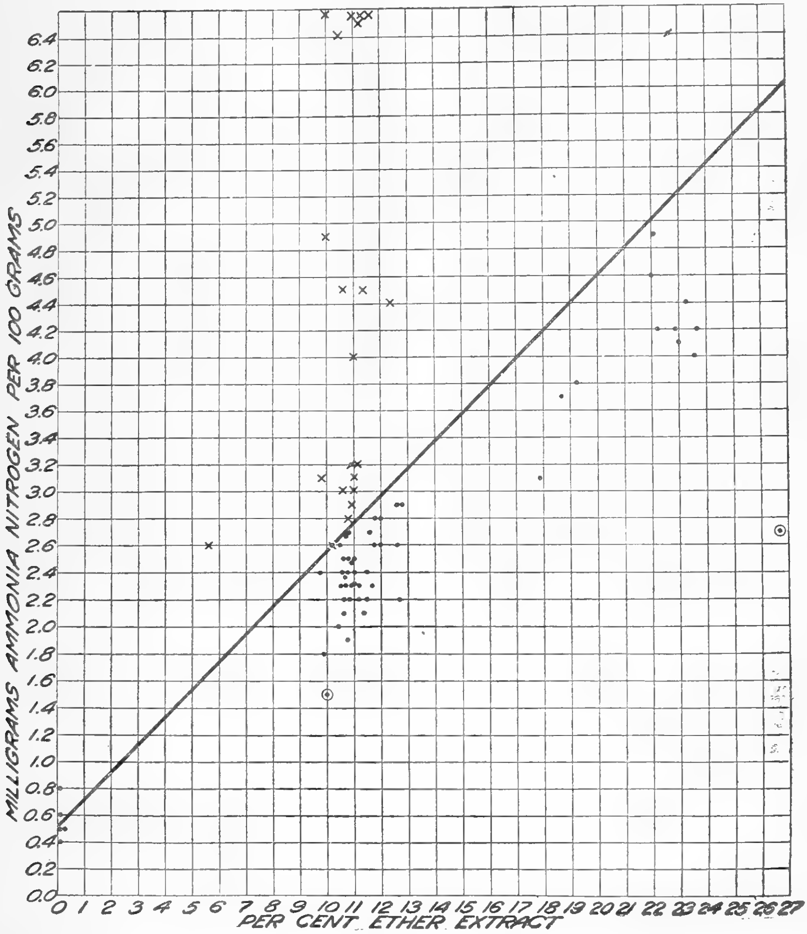

Fig. 1.—Ammonia nitrogen results.

shown by dots, while crosses have been used for the results from inedible samples. In the case of border-line or questionable samples, each result has been indicated by a dot with a line drawn through it.

A line, which separates very well the dots from the crosses, has been so located that all of the dots are below it, with the exception of two at the extreme left of the chart which represent white and undoubtedly are due to analytical errors. The dots and crosses between 9.5 and 13 per cent of ether extract represent whole egg. Within these limits the maximum amount of ammonia nitrogen, as indicated by the line, varies from 2.45 to 3.16 milligrams per 100 grams. The dots between 22 and 24 per cent of ether extract indicate yolk, and in these samples the maximum ammonia nitrogen varies from 5 to 5.4 milligrams per 100 grams. The encircled dot at the intersection of 26.65 per cent of ether extract and 2.7 milligrams of ammonia nitrogen represents yolk from the freshest eggs obtainable. The corresponding dot for whole egg is at the intersection of 10 per cent of ether extract and 1.5 milligrams of ammonia nitrogen. The distance below the line at which these dots are located is noteworthy. The dots in the neighborhood of 18 and 19 per cent of ether extract represent sugared yolk, and the cross at the intersection of 5.7 per cent ether extract and 2.6 milligrams of ammonia nitrogen represents drip.

As almost all of these results were obtained from August eggs, when eggs are in the poorest condition, there can be no reason to believe that the ammonia nitrogen figures for edible material will be appreciably above the line at any season of the year. The line is applicable for white, whole egg, yolk, or yolky mixtures made from fresh or storage eggs.

To carry such a plot continually around in order to ascertain whether the result for ammonia nitrogen of any sample would fall above or below the line would be inconvenient. Moreover, some form of expression which can be used in forming a composite picture of all of the different analytical results is very desirable. The proper mathematical expression for the line is evidently what is needed. The expression for such a line is

$$Y-Y'=\frac{Y'-Y''}{X'-X''}(X-X') \quad \text{or} \quad R-R'=\frac{R'-R''}{Q'-Q''}(Q-Q')$$

Widely separated values for R', Q', R'', and Q'' were selected from the plot as follows:

$$R'=0.5 \qquad Q'=0.0 \qquad R''=5.0 \qquad Q''=22.0$$

These values establish the position of the line, whether analytical results or not. Then

$$R-0.5=\frac{0.5-5.0}{0.0-22.0}(Q-0.0)$$

and the vertical distance of any point from this line, in terms of milligrams of ammonia nitrogen per 100 grams of sample, will be

$$D=R-0.5-\left[\frac{0.5-5.0}{0.0-22.0}(Q-0.0)\right]$$

Solving this equation, it becomes

$$D=R-0.205\ Q-0.5$$

If dealing with a sample of unknown quality, substitute for R in the equation the milligrams of ammonia nitrogen per 100 grams of sample on the wet basis, and for Q the percentage of ether extract. If on solving it, the result is less than zero, the sample contains less ammonia nitrogen for the amount of ether extract involved than was found to be the maximum amount in the samples examined in this investigation, and may be considered edible as far as ammonia nitrogen is concerned, although the determinations of other constituents might show it to be inedible. Obviously, the magnitude of the figure measures the quality of the sample, in respect to this one constituent. If on solving, the result is more than zero, the converse interpretation is applicable.

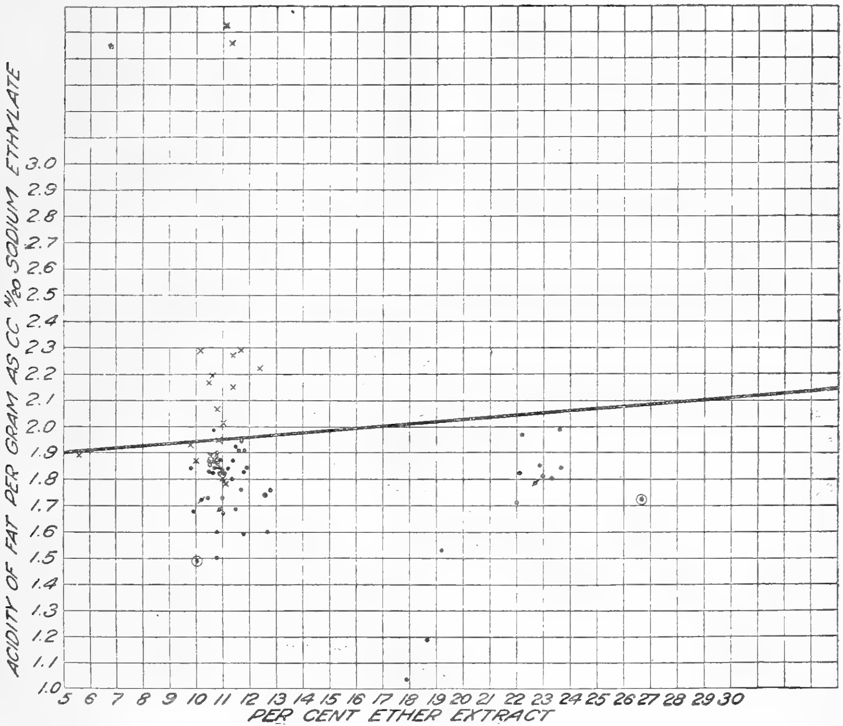

FIG. 2—Acidity of fat results.

ACIDITY OF THE FAT.

As has already been pointed out, the acidity of the fat is normally slightly higher in yolk than in whole egg of the same quality, although theoretically there should be no difference. It is therefore logical, as in the case of ammonia nitrogen, to plot the acidity of the fat against the ether extract, expressing the acidity as the equivalent number of cubic centimeters of N/20 sodium ethylate per gram of fat and the ether extract as per cent. The plot will hold for yolky mixtures, as well as for whole egg or yolk, prepared from either fresh eggs or storage eggs.

Such a plot of the results in Tables 1 to 23 is given in figure 2, the dots and crosses having the same significance as in the ammonia nitrogen plot (fig. 1). A line separating them has been drawn, leaving six crosses below the line, and one dot above it. If there were six dots above the line and one cross below it, the position of the line might with justice be criticised. The fact that there are six crosses below the line, however, merely shows that, in those particular samples, the decomposition was not of a lipolytic nature, but was of a proteolytic or fermentative nature.

The dots and crosses between 9.5 and 13 per cent of ether extract represent whole egg. Within those limits the maximum amount of acidity of the fat, as indicated by the line, varies from 1.94 to 1.97 cubic centimeters of N/20 sodium ethylate required per gram. The dots between 22 and 24 per cent of ether extract, representing yolk, show a corresponding variation for acidity of the fat from 2.04 to 2.06 cubic centimeters of the N/20 sodium ethylate required per gram. The dot at the intersection of 26.65 per cent of ether extract and 1.72 cubic centimeters sodium ethylate required stands for yolk from the freshest eggs obtainable. The corresponding dot for whole egg lies at the intersection of 10 per cent of ether extract and 1.49 cubic centimeters required. The distance below the line at which these dots are located should be noted. The dots in the neighborhood of 18 and 19 per cent of ether extract represent sugared yolk, while the cross at the intersection of 5.7 per cent of ether extract and 1.89 cubic centimeters of N/20 sodium ethylate required represents drip.

Again, widely separated values are selected from the plot:

$Q'=5.0 \qquad S'=1.90 \qquad Q''=29.0 \qquad S''=2.10$

These may be substituted in the straight-line expression

$$S-S'=\frac{S'-S''}{Q'-Q''}(Q-Q')$$

to give

$$S-1.90=\frac{1.90-2.10}{5.0-29.0}(Q-5.0)$$

The vertical distance of any point from this line in terms of cubic centimeters N/20 sodium ethylate required per gram of fat will be

$$D'=S-1.90-\left[\frac{1.90-2.10}{5.0-29.0}(Q-5.0)\right]$$

Solving this equation, it becomes

$$D'=S-0.008Q-1.858$$

If dealing with a sample of unknown quality, the actual values for acidity of the fat and ether extract are substituted for S and Q, respectively, and the result is interpreted as explained under the ammonia nitrogen plot (p. 63).

REDUCING SUGAR.

As the reducing sugar is a part of the egg solids not fat, it is plotted in figure 3 against the differences between the total solids and the sums of the ether extract, sucrose, and salt, all factors being expressed as percentage on the wet basis. While no determinations of sucrose and salt were made, the amounts alleged to be present by the manufacturers were assumed to be present in those samples containing sucrose or salt.

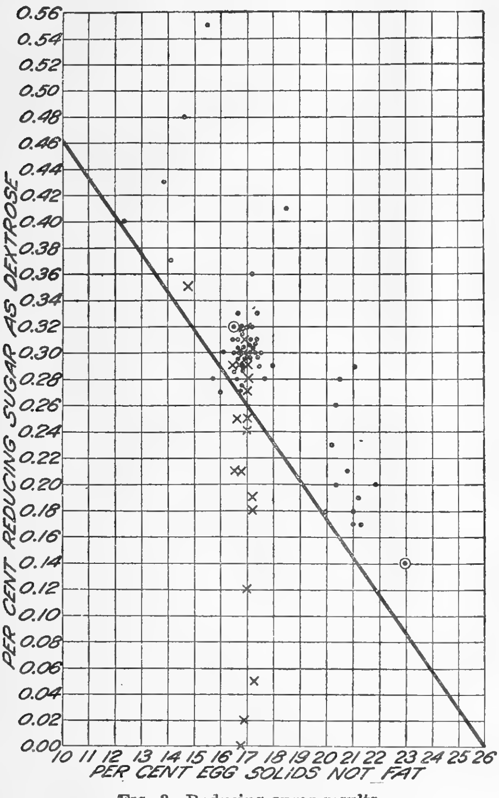

FIG. 3—Reducing sugar results.

As in the other plots, a line has been drawn to separate the dots and crosses. In the case of reducing sugar, where decomposition is accompanied by a decrease instead of an increase, all the dots should be above the line. All are above, except two which are relatively close to the line. It will be noted that eight crosses are above the line, for which fact an interpretation analogous to that given under acidityof the fat (p. 64) is advanced, namely, that in those particular samples the decomposition was not of a fermentation character, but was of a proteolytic or lipolytic nature.

The majority of the dots and crosses for whole egg lie between 16 and 18.5 per cent of egg solids not fat. Within those limits the minimum percentages of reducing sugar, as shown by the line, vary from 0.288 to 0.216. The dots between 20 and 23 per cent of egg solids not fat represent yolk. Within these limits the minimum corresponding amounts of reducing sugar vary from 0.172 to 0.086 per cent. The dots for sugared yolk are very close to 20 per cent of egg solids not fat, and vary between 0.28 and 0.26 per cent of reducing sugar. The equation for the line in this case is:

$$U-U'=\frac{U'-U''}{T'-T''}(T-T')$$

which, on substituting the widely separated values,

$U'=0.46$ $T'=10.0$ $U''=0.0$ $T''=26.0$

becomes

$$U-0.46=\frac{0.46-0.0}{10.0-26.0}(T-10.0)$$

The vertical distance of any point from this line in terms of percentage of reducing sugars will be

$$D''=U-0.46-\left[\frac{0.46-0.0}{10.0-26.0}(T-10.0)\right]$$

Solving this equation it becomes

$$D''=U+0.029T-0.748$$

If dealing with a sample of unknown quality, substitute the values found for reducing sugars and egg solids not fat for U and T, respectively, and give the converse interpretation to that explained under the ammonia nitrogen plot (p. 63).

COMPOSITE RESULTS.

In deciding whether or not a frozen egg product is edible and may pass freely into commerce, it is only in extreme cases that dependence can be placed upon the determination of any one constituent. In ordinary cases, all the analytical figures must be considered in their relation to one another. If, therefore, the values of D, D', and D'' (pp. 62, 64, 66) can be grouped into a composite whole, and factors can be added for the bacterial content, for the *B. coli* content, and for the presence of indol or skatol, of mold clumps, and of embryos, and if the proper relative weights can be found for the different factors, a definite, nonvarying basis of interpretation is provided. The relative weights must be such as to insure a final result which will be less than zero for each of the samples in Tables 1 to 23 considered edible, as well as a proper article of commerce by the experts who made them or saw them made, and which will be greater than zero for each of the samples made from inedible raw materials according to the judgment of these same experts.

Consequently, a rather lengthy series of trials has been made, with the purpose of evolving such a composite expression on what is really a bonus and penalty system. It has been impossible to devise a formula which would separate absolutely the two classes of products. By giving the manufacturer the benefit of the doubt in the border-line cases, however, the following formula has been found to serve admirably for white, whole egg, yolky mixtures, and unsugared yolk, prepared from fresh eggs or storage eggs. It applies, of necessity, only to egg material to which no gross addition of foreign material has been made and which can be recognized by the fact that in white, yolk, whole egg, or yolky mixture, the total nitrogen should amount to 12 to 14 per cent of the solids not fat.

$$10.0D+10.0D'-25.0D''+V+\frac{W}{5,000,000}+\frac{X}{500,000}+Y+Z=0$$

or

$$10.0(R-0.205Q-0.5)+10.0(S-0.008Q-1.858)-25.0\ (U+0.029T-0.748)+V+\frac{W}{5,000,000}+\frac{X}{500,000}+Y+Z=0$$

Q = Per cent ether extract, wet basis.

R = Milligrams ammonia nitrogen per 100 grams, wet basis.

S = Acidity of the fat per gram, as cubic centimeters N/20 sodium ethylate required.

T = Per cent egg solids not fat, wet basis.

U = Per cent reducing sugar, as dextrose, wet basis.

V = 5, if indol or skatol present; 0.0, if absent.

W = Number of bacteria per gram, wet basis, developing on plain agar, at 20° C. in 5 days.

X = Number of confirmed *B. coli* per gram, wet basis, producing 10 per cent or over of gas in lactose broth, at 37° C. in 2 days.

Y = 1 for each mold clump found per 30 pounds of egg material.

Z = 0.5 for each embryo found per 30 pounds of egg material.

An explanation of how the values for V, $\frac{W}{5,000,000}$, $\frac{X}{500,000}$, Y, and Z were determined is necessary.

The value of 5 for V, if indol or skatol was found present, was reached by substituting for V different values in the formula until the proper value was found.

The divisor in $\frac{W}{5,000,000}$ was decided upon by entering on a chart (fig. 4), against the number of bacteria present, a dot if the sample was considered edible, a cross if it was considered inedible, and a dot with a line through it if it was considered of questionable character. It is understood that dividing W by any divisor and adding the result to the formula gives a figure which places a penalty upon the presence of any bacteria. This is as it should be, since theoretically there should be no bacteria present. Practically, it is impossible, unless the aseptic precautions of the bacteriological laboratory are employed, to open eggs without introducing bacteria. Such aseptic precautions can not be followed in a commercial egg-breaking plant. As the magnitude of the divisor determines the magnitude of the penalty to be imposed, it should be fairly large. It was decided to make the divisor 5,000,000, so that a penalty of unity would be placed upon any sample containing

5,000,000 bacteria, with a penalty of more than unity if more than 5,000,000 bacteria were present and vice versa. In the chart (fig. 4) there are 8 dots above the 5,000,000 line and 3 crosses below it. The penalty imposed in the case of samples with dots above this line is not sufficiently great to cause any of them to have a formula value greater than zero. The choice of 5,000,000 is further vindicated by the extensive experiences of three members of the Bureau of Chemistry in examining commercial frozen egg products and by the narrated experiences of a bacteriologist in a commercial egg-breaking plant who stated that in his opinion no frozen egg product should contain more than 5,000,000 bacteria at any season of the year.

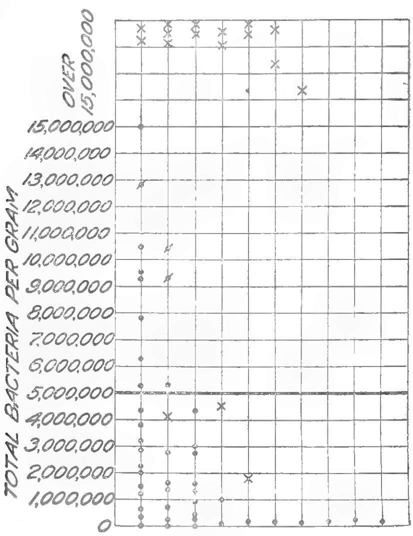

FIG. 4.—Total bacterial counts.

The divisor in $\frac{X}{500,000}$ was determined in a similar manner (fig. 5).

The values assigned to Y and Z are in conformity with what juries and judges have been found to tolerate or condemn in the past, and are also in accord with the 5 per cent bad-egg ruling of the Department of Agriculture.

For sugared yolk, which may be recognized by the fact that the solids not fat will be almost double the ether extract, as compared with approximately equal amounts of these two constituents in the case of unsugared yolk, this formula must be modified to the following form, based upon the plots:

$$10.0\ (R-0.205Q-0.5)+10.0\ (S-0.008Q-1.158)-25.0\ (U+0.029T-0.798)+V+\frac{W}{5,000,000}+\frac{X}{500,000}+Y+Z=0$$

It is important to see how these formulas actually work out in practice. At the bottom of Tables 1 to 23 will be found the formula values for the samples, the formula being calculated in each case for the average of the results of the individual analysts. In Tables 1, 2, and 3 the formula values are negative, and of a very appreciable magnitude. In Table 4 the formula value is small, as would be expected in all samples of egg white. In Table 5 all the values are negative, and decrease in magnitude with the length of time the eggs were held in storage. It will be noted that in the first three formula values there are terminal plus signs. These indicate that it probably would have been necessary to make an addition to the formula, if a bacteriological examination had been made. This explanation applies wherever a terminal plus is found in a formula value.

In Table 6 there is a regular progression from a good-sized negative value to a positive value as the length of time in storage increases. That a positive value was obtained for the yolk from eggs held in storage for the longest period of time, while a negative value was found for whole egg made from the same raw material, is somewhat inconsistent. It might be argued that it is fair because the yolk decomposes more readily than the white which is included in the whole egg. On the other hand, however, if the yolk is really decomposed, the whole egg containing it should not be considered edible. The advisability of proposing a separate formula for yolk from storage eggs in order to obtain a negative value for this yolk was considered, but was discarded, because the fewer the formulas the better. Moreover, the present formula gives negative values for the yolk from eggs held in storage for 8 months, and presumably would give similar results for eggs held 10 months, probably the longest period for which eggs used for making frozen yolk would be held. Possibly such raw material might be used for whole egg but not for yolk.

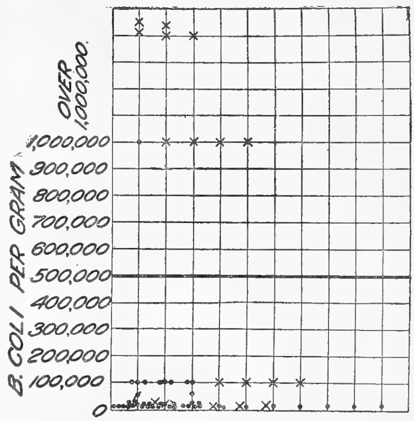

FIG. 5.—*B. coli* counts.

Table 7 shows all white from storage eggs with negative values, or with results so slightly above zero as to be accounted for by analytical errors. Table 8 shows all samples of experimental first-grade whole egg with negative values, even with bacterial contents as high as 10,500,000 per gram. The uniformity of analytical results, and especially of formula values, of these samples prepared from a wide variety of raw materials and in three different factories is noteworthy. The formula values for the commercial first-grade whole egg are given in Table 9. These samples were prepared in the same factories and from the same raw materials as the samples in Table 8 with which they are entirely comparable. It should be noted that all the values are negative, and that the samples were made from August eggs, the poorest eggs of the year.

All the samples of commercial first-grade whole egg containing sugar and salt in Table 10 gave negative formula values, even with bacterial contents as high as 15,000,000 per gram. All the samples of experimental and commercial soft-grade whole egg found in Tables 11 and 12 show negative formula values.

As previously pointed out, an attempt was made by the manufacturers who cooperated in this work and by the Bureau representatives to separate edible breaking stock into two portions, one designated as first grade to be of higher quality than the other designated as soft grade. The formula values for these four groups of samples, as given in Tables 8, 9, 11, and 12, show variations between the following limits, −9.24 to −4.11, −7.12 to −3.17, −7.33 to −4.17, and −9.88 to −1.44, and indicate very strongly that such grading is impossible with breaking stock eggs, as the variation within each group was far greater than was the variation between the different groups. All samples prepared from leakers as given in Table 13 have negative formula values, the one of least magnitude being the one prepared under the most unfavorable conditions. Tables 14, 15, and 16 for yolks show negative formula values, with but small range of magnitude.

This completes the results obtained for samples considered edible by the Bureau representatives who made them or saw them made, and for which the formula values are less than zero. The questionable and inedible samples described in Tables 17 to 23 should show values very close to zero or greater than zero if the formula is reliable.

Table 17 contains the results of analysis of samples of experimental second-grade whole egg. All the formula values are positive, except that for sample 32 which was a low first rather than a second-grade product. The leniency of the formula is shown in Table 18, in which two of the samples of commercial second-grade egg have negative values, even though one of them contained 17,500,000 bacteria per gram. This sample was prepared from April eggs, a fact which helps materially in explaining the chemical figures. It probably represents a low first rather than a second-grade product.

Tables 19 and 20 show high positive values. The formula value for drip given in Table 21 is an index of the character of this product. In Table 22 are collected the results of the examination of samples made from different types of eggs considered inedible unmixed with other eggs. All have positive formula values. Table 23 shows decomposition due to delay in freezing. The progressive change from negative to positive values is interesting. The values for samples 62 and 63 are for badly decomposed material.

SUMMARY OF RESULTS.

To summarize, the formula separates the samples into edible and inedible groups which agree with the classification based upon the known quality of the raw materials from which they were made. If the formula errs in either direction, it is in the direction of leniency.

In order to make comparisons easier, the average results for the different groups of egg products, with the formula values for such averages, have been gathered together in Tables 24 and 25.

TABLE 24.—*Summary of results of examination of eggs considered edible.*

Description of groups of samples.	Total solids (wet basis).	Ether extract (wet basis).	Total solids minus ether extract, sucrose, and salt.	Ammonia nitrogen (wet basis), titration method	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol and skatol.	Organisms per gram.					Formula value.
								Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, lactose litmus agar, 37° C., 48 hours.	Alkali producers, lactose litmus agar, 37° C., 48 hours.	Confirmed *B. coli.*	
(1) Experimental whole egg. Prepared in laboratories from best fresh eggs obtainable. (Table 1):	*Per ct.*	*Per ct.*	*Per ct.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per ct.*							
Average	26.54	10.00	16.54	1.5	1.49	0.32	0	0	0	....	....	0	—16.27
Maximum	27.19	11.01	16.65	2.0	1.72	.36	0	0	0	....	....	0	....
Minimum	25.96	9.31	16.18	1.0	1.21	.29	0	0	0	....	....	0	....
(2) Commercial whole egg. Freshly prepared from May eggs. (Table 2):													
Average	27.59	10.28	17.31	2.0	1.80	....	....	1,500,000	1,000,000	....	....	....	—7.18
Maximum	28.57	11.20	17.37	2.3	1.91	....	....	4,400,000	3,700,000	....	....	....	....
Minimum	26.78	9.66	17.12	1.6	1.66	....	....	70,000	17,000	....	....	....	....
(3) Experimental first-grade whole egg. No sugar or salt. (Table 8):													
Average	27.85	10.97	16.88	2.2	1.87	.29	0	4,000,000	1,800,000	230,000	22,000	17,500	—6.20
Maximum	29.05	11.53	17.52	2.4	1.92	.31	0	10,500,000	4,900,000	550,000	100,000	100,000	....
Minimum	27.09	10.55	16.54	1.9	1.84	.27	0	120,000	80,000	20,000	0	100	....
(4) Commercial first-grade whole egg. No sugar or salt. (Table 9):													
Average	28.24	11.26	16.98	2.5	1.82	.31	0	2,600,000	1,600,000	320,000	90,000	100,000	—5.00
Maximum	28.91	11.78	17.13	2.8	1.95	.32	0	5,300,000	2,900,000	660,000	260,000	550,000	....
Minimum	27.29	10.45	16.84	2.3	1.73	.29	0	160,000	25,000	0	0	100	....
(5) Commercial first-grade whole egg. 1 per cent sugar, 0.7 per cent salt. (Table 10):													
Average	28.89	10.89	16.30	2.3	1.75	.30	0	6,500,000	2,200,000	850,000	0	220,000	—5.00
Maximum	29.37	11.48	16.67	2.5	1.90	.31	0	15,000,000	5,850,000	850,000	0	1,000,000	....
Minimum	27.71	9.91	15.10	1.8	1.67	.28	0	340,000	20,000	850,000	0	100	....
(6) Experimental soft-grade whole egg. No sugar or salt. (Table 11):													
Average	27.62	10.93	16.69	2.3	1.83	.30	0	3,600,000	850,000	97,000	3,000	67,000	—5.61
Maximum	27.82	11.22	16.69	2.5	1.84	.32	0	9,300,000	2,300,000	130,000	10,000	100,000	....
Minimum	27.26	10.65	16.60	2.1	1.82	.28	0	320,000	110,000	60,000	0	550	....
(7) Commercial soft-grade whole egg. No sugar or salt. (Table 12):													
Average	26.81	10.28	16.53	2.3	1.85	.31	0	1,600,000	1,900,000	5,000	0	18,500	—4.65
Maximum	27.35	10.66	16.69	2.4	1.99	.33	0	3,800,000	4,700,000	10,000	0	55,000	....
Minimum	25.81	9.83	15.98	2.0	1.73	.27	0	130,000	90,000	0	0	100	....

(8) Experimental whole egg. Prepared from leakers. No sugar or salt. (Table 13):													
Average	29.58	12.24	17.34	2.6	1.69	.30	0	8,800,000	1,700,000	53,000	0	50,000	−6.26
Maximum	30.30	12.71	17.59	2.8	1.84	.30	0	12,800,000	2,600,000	100,000	0	100,000	....
Minimum	28.68	11.78	16.90	2.2	1.59	.28	0	2,000,000	950,000	5,000	0	100	....
(9) Experimental yolk. Prepared in laboratories from best fresh eggs obtainable. (Table 3):													
Average	49.69	26.66	23.03	2.7	1.72	.14	0	0	0	....	....	....	−36.66
Maximum	50.90	28.78	24.01	3.1	1.96	.20	0	0	0	....	....	....	....
Minimum	46.93	24.49	22.44	2.5	1.44	.08	0	0	0	....	....	....	....
(10) Experimental first-grade yolk. No sugar. (Table 14):													
Average	43.31	23.14	20.17	4.2	1.81	.19	0	260,000	220,000	0	0	550	−13.36
Maximum	43.42	23.25	20.17	4.4	1.81	.20	0	280,000	270,000	0	0	1,000	....
Minimum	43.19	23.03	20.16	4.1	1.80	.18	0	240,000	160,000	0	0	100	....
(11) Commercial first-grade yolk. No sugar. (Table 15):													
Average	44.19	23.08	21.11	4.1	1.91	.18	0	2,500,000	1,000,000	....	....	26,500	−13.19
Maximum	44.84	23.69	21.15	4.2	1.99	.20	0	5,300,000	2,200,000	....	....	100,000	....
Minimum	43.10	22.18	20.92	4.0	1.84	.17	0	270,000	140,000	....	....	100	....
(12) Commercial first-grade yolk. 10 per cent sugar. (Table 16):													
Average	48.76	18.35	20.41	3.4	1.13	.27	0	600,000	240,000	....	....	5,500	−11.82
Maximum	49.06	18.65	20.52	3.7	1.19	.28	0	950,000	450,000	....	....	10,000	....
Minimum	48.46	17.94	20.32	3.1	1.04	.26	0	220,000	20,000	....	....	1,000	....
(13) Experimental white. Prepared in laboratories from best fresh eggs obtainable. (Table 4):													
Average	12.35	.05	12.30	.5	....	.40	0	0	0	....	....	....	−0.32
Maximum	12.83	.12	12.71	1.2	....	.46	0	0	0	....	....	....	....
Minimum	11.80	.01	11.79	.0	....	.31	0	0	0	....	....	....	....

TABLE 25.—*Summary of results of examination of eggs considered inedible.*

Description of groups of samples.	Total solids (wet basis).	Ether extract (wet basis).	Total solids minus ether extract, sucrose, and salt (wet basis).	Ammonia nitrogen (wet basis), titration method	Acidity of fat as N/20 sodium ethylate.	Reducing sugar as dextrose (wet basis).	Indol and skatol.	Organisms per gram.					Formula value.
								Plain agar, 20° C., 120 hours.	Plain agar, 37° C., 48 hours.	Acid producers, lactose litmus agar, 37° C., 48 hours.	Alkali producers, lactose litmus agar, 37° C., 48 hours.	Confirmed *B. coli*.	
	Percent.	*Percent.*	*Percent.*	*Mg. per 100 grams.*	*Cc. per gram.*	*Per cent.*							
(1) Experimental second-grade whole egg. No sugar or salt (Table 17):													
Average	27.73	10.73	17.00	2.7	1.90	0.31	0	47,500,000	20,900,000	3,300,000	2,300,000	370,000	+ 8.43
Maximum	28.75	11.62	17.13	3.1	1.95	.31	0	105,500,000	53,000,000	8,000,000	2,300,000	1,000,000	
Minimum	26.68	9.79	16.11	2.2	1.82	.30	0	4,100,000	3,800,000	900,000	2,200,000	1,000	
(2) Commercial second-grade whole egg. No sugar or salt (Table 18):													
Average	28.38	11.44	16.94	3.7	1.88	.28	0	76,500,000	14,400,000	3,500,000	200,000	220,000	+23.01
Maximum	29.45	12.44	17.01	4.4	2.22	.32	0	211,000,000	58,000,000	10,000,000	500,000	1,000,000	
Minimum	27.13	10.18	16.95	2.6	1.72	.25	0	380,000	800,000	100,000	0	5,500	
(3) Experimental tanners' grade whole egg. No sugar or salt (Table 19):													
Average	27.59	10.64	16.95	3.0	1.89	.25	+	16,300,000	4,000,000	2,000,000	200,000	100,000	+11.28
Maximum	27.59	10.64	16.95	3.0	1.89	.25	+	16,300,000	4,000,000	2,000,000	200,000	100,000	
Minimum	27.59	10.64	16.95	3.0	1.89	.25	+	16,300,000	4,000,000	2,000,000	200,000	100,000	
(4) Commercial tanners' grade whole egg. No sugar or salt (Table 20):													
Average	27.09	10.38	16.71	6.8	2.24	.21	+	279,300,000	156,000,000	28,000,000	83,000,000	10,000,000	+126.91
Maximum	27.36	10.53	16.83	7.2	2.29	.21	+	360,000,000	211,000,000	28,000,000	83,000,000	10,000,000	
Minimum	26.76	10.20	16.56	6.4	2.18	.21	0	198,500,000	101,000,000	28,000,000	83,000,000	10,000,000	
(5) Commercial drip. No sugar or salt (Table 21)	20.44	5.62	14.82	2.6	1.89	.35	0	63,500,000	20,500,000			1,000,000	+23.25
(6) Experimental whole egg. Prepared from cracked eggs with moldy shells (Table 22)	27.18	10.65	16.53	2.4	1.87	.27	+	4,500,000	900,000	100,000	0	10,000	+ 2.32
(7) Experimental whole egg. Prepared from eggs with slightly stuck yolks (Table 22)	27.86	10.83	17.03	2.8	2.07	.29	0						+ 1.14
(8) Experimental whole egg. Prepared from eggs with slightly disintegrated yolks (border-line rots) (Table 22)	27.71	11.01	16.70	3.1	2.01	.29	0						+ 3.41+
(9) Experimental whole egg. Prepared from eggs which were partially addled (mixed rots) (Table 22)	28.39	11.40	16.99	4.5	2.15	.24	0						+19.02+
(10) Experimental whole egg. Prepared from eggs which were sour (Table 22)	27.79	10.64	17.15	4.5	2.19	.19	0	397,000,000	370,000,000	24,000,000	135,000,000	10,000,000	+121.57+

(11) Experimental whole egg. Prepared from eggs with green whites (Table 22)	27.24	10.02	17.22	4.9	1.87	.18	0	285,000,000	213,500,000	35,000,000	40,000,000	10,000,000	+101.49
(12) Experimental whole egg. Prepared from eggs which were completely addled (white rots) (Table 22)	28.34	11.38	16.96	12.8	3.46	.12	+	.....	.....	.....	.....	.....	+123.18+
(13) Experimental whole egg. Prepared from eggs with heavily stuck yolks (Table 22)	28.38	11.12	17.26	12.8	6.61	.05	+	.....	.....	.....	.....	.....	+156.77+
(14) Experimental decomposing whole egg. Put in freezer after holding for 23 hours at 66° F. (Table 23)	28.59	11.70	16.89	6.7	2.29	.02	0	284,500,000	293,500,000	280,000,000	12,000,000	10,000,000	+126.05
(15) Experimental decomposing whole egg. Put in freezer after holding for 29½ hours at 66° F. (Table 23)	28.14	11.38	16.76	8.2	2.27	.00	0	250,000,000	238,000,000	140,500,000	11,100,000	1,000,000	+115.43

The results presented in Tables 24 and 25 are summarized even more briefly in Table 26.

TABLE 26.—*Limits of variation found.*

Determination.	Whole egg.			
	Freshest obtainable. Opened aseptically. June and July eggs.	Held in cold storage from 4 to 13 months. Opened aseptically. April and May eggs.	Regular breaking stock. Considered edible. Opened commercially. August eggs.	Breaking stock. Considered inedible. Opened commercially. August eggs.
Total solids (per cent)	25.96 to 27.19	27.88 to 29.34	25.81 to 30.30	26.68 to 29.45
Ether extract (per cent)	9.31 to 11.01	10.52 to 10.88	9.66 to 12.71	9.79 to 12.44
Total solids minus ether extract, sucrose, and salt (per cent)	16.18 to 16.65	17.36 to 18.46	15.98 to 18.19	16.11 to 17.26
Ammonia nitrogen (mg. per 100 grams)	1.0 to 2.0	2.6 to 3.2	1.6 to 2.8	2.2 to 12.8
Acidity of fat (cc. N/20 sodium ethylate per gram)	1.21 to 1.72	1.50 to 1.83	1.59 to 1.99	1.72 to 6.61
Reducing sugar (per cent)	0.29 to 0.36	0.31 to 0.41	0.27 to 0.33	0.00 to 0.31
Bacteria, 20° C., 5 days	0.0 to 0.0	0.0 to 0.0	70,000 to 15,000,000	380,000 to 397,000,000
Acid producers, 37° C., 2 days	....	....	0.0 to 850,000	100,000 to 280,000,000
Alkali producers, 37° C., 2 days	....	....	0.0 to 260,000	0.0 to 135,000,000
B. coli, 37° C., 2 days	0.0 to 0.0	....	100 to 1,000,000	1,000 to 10,000,000

Determination.	Yolk.		
	Freshest obtainable. Opened aseptically. June and July eggs.	Held in cold storage from 4 to 13 months. Opened aseptically. April and May eggs.	Regular breaking stock. Considered edible. Opened commercially. August eggs.
Total solids (per cent)	46.93 to 50.90	39.43 to 43.87	43.10 to 44.84
Ether extract (per cent)	24.49 to 28.78	19.24 to 22.74	22.18 to 23.69
Total solids minus ether extract, sucrose, and salt (per cent)	22.44 to 24.01	20.19 to 21.13	20.16 to 21.15
Ammonia nitrogen (mg. per 100 grams)	2.5 to 3.1	3.8 to 6.4	4.0 to 4.4
Acidity of fat (cc. N/20 sodium ethylate per gram)	1.44 to 1.96	1.53 to 1.82	1.80 to 1.99
Reducing sugar (per cent)	0.08 to 0.20	0.18 to 0.29	0.17 to 0.20
Bacteria, 20° C., 5 days	0.0 to 0.0	0.0 to 87,000	240,000 to 5,300,000
Acid producers, 37° C., 2 days	....	....	0.0 to 0.0
Alkali producers, 37° C., 2 days	....	....	0.0 to 0.0
B. coli, 37° C., 2 days	....	0.0 to 0.0	100 to 100,000

Determination.	Sugared yolk.	White.	
	Regular breaking stock. Considered edible. Opened commercially. August eggs.	Freshest obtainable. Opened aseptically. June and July eggs.	Held in cold storage from 4 to 13 months. Opened aseptically. April and May eggs.
Total solids (per cent)	48.46 to 49.06	11.80 to 12.83	13.96 to 15.54
Ether extract (per cent)	17.94 to 18.65	0.01 to 0.12	0.03 to 0.07
Total solids minus ether extract, sucrose, and salt (per cent)	20.32 to 20.52	11.79 to 12.71	13.92 to 15.51
Ammonia nitrogen (mg. per 100 grams)	3.1 to 3.7	0.0 to 1.2	0.4 to 0.8
Acidity of fat (cc. N/20 sodium ethylate per gram)	1.04 to 1.19	....	....
Reducing sugar (per cent)	0.26 to 0.28	0.31 to 0.46	0.37 to 0.55
Bacteria, 20° C., 5 days	220,000 to 950,000	0.0 to 0.0	0.0 to 110,000
Acid producers, 37° C., 2 days	....	....	....
Alkali producers, 37° C., 2 days	....	....	....
B. coli, 37° C., 2 days	1,000 to 10,000	....	0.0 to 0.0

METHODS OF EXAMINATION OF SAMPLES.

METHODS TESTED.

In the course of the preliminary preparation and examination of samples in the laboratories numerous questions arose concerning the details of the analytical methods. During the examination of samples prepared in egg-breaking plants, and subsequently, experiments were performed to settle these questions, a short discussion of which would seem proper at this place, to save the time of chemists who, not knowing that such experiments had already been made, might again cover the same ground.

USE OF SAND IN THE DETERMINATION OF TOTAL SOLIDS.

One of the analysts who tried this procedure in his preliminary work reported that he considered the use of sand an improvement, in that the drying period was generally shortened, the final results being the same with sand and without, in the case of whole egg. With yolk, the results were invariably found to be higher when no sand was used, presumably due to incomplete drying. With white, the results were reported as inconclusive. It was noted that due to other demands on the suction pump, the average vacuum was only 22 inches, which is believed to be the explanation for the difficulty with yolk.

TABLE 27.—*Percentage of total solids obtained when sample is dried with and without sand.*

Sample No.	Whole egg.			
	Dried with 10 grams sand in 3-inch lead dish.		Dried without sand in 3-inch lead dish.	
	A.	B.	A.	B.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
3972	26.98	26.86	27.00	27.01
3973	26.04	26.14	26.12	26.26
3974	26.27	26.12	26.35	26.39
3975	26.61	26.75	26.80	26.78
4476	26.52	26.45	26.56	26.56
Average	26.47		26.58	

Sample No.	Yolk.				White.			
	Dried with 5-10 grams sand in 3-inch lead dish.		Dried without sand in 3-inch lead dish.		Dried with 5-10 grams sand in 3-inch lead dish.		Dried without sand in 3-inch lead dish.	
	A.	B.	A.	B.	A.	B.	A.	B.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
4477	50.49	50.46	50.78	50.76	12.78	12.93	12.78	Lost
4478	50.82	50.90	50.99	50.91	12.35	12.29	12.36	12.36
4479	50.52	50.58	50.79	50.79	12.79	12.85	12.82	12.83
4480	50.13	49.90	50.51	50.42	12.04	12.04	12.26	12.22
4481	50.51	50.45	50.81	51.03	12.56	12.53	12.83	12.85
Average	50.48		50.78		12.52		12.60	

In the opinion of the chemists who finally passed upon the methods, the slight differences in results do not warrant the extra labor connected with the use of sand.

Amount of Sample to be Used for Total Solids Determination.

The reason for investigating this matter was connected primarily with the determinations of ether extract and of acidity of the fat which it was considered might be made more accurate by using larger amounts of sample. The question then arose as to whether these larger amounts of sample could be completely dried to give correct total solids. The results obtained are given in Table 28.

Table 28.—*Percentage of total solids obtained with varying amounts of sample.*

Sample No.	Initial of analyst.	Using 2.5± grams.		Using 5.0± grams.	
		A.	B.	A.	B.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
16	B	27.59	27.68	27.63	27.68
	D	27.57	27.71	27.13	27.12
	E	27.32	27.17	27.16	27.21
	H	26.73	30.04	26.86	28.90
	S	27.72	27.50	27.32	27.42
18	B	29.58	29.77	29.60	29.61
	D	31.77	30.34	29.75	29.83
	E	29.06	28.86	28.92	28.88
	H	29.09	28.69	28.45	28.73
	S	29.97	30.41	29.90	30.02
1	D	30.36	29.92	29.83	29.99
	E	31.27	30.66	30.69	30.84
	H	30.32	30.35	30.44	30.33
	S	29.46	29.51	28.55	29.94
3	D	29.24	29.38	28.75	28.82
	E	29.12	29.23	29.06	28.99
	H	28.53	28.23	28.41	28.31
	S	29.00	28.81	28.44	28.65
15	D	21.22	21.05	20.88	20.84
	E	19.58	19.47	19.61	19.44
	H	20.55	20.10	20.01	20.37
	S	21.57	21.79	21.55	21.63
Average		27.58		27.31	

There is not much difference in the results obtained by the two methods, but what little difference there is indicates the desirability of using the larger amount, as it gives more uniform results, presumably due to decrease in the percentage error.

Determination of Ether Extract from the Solids Dried With and Without Sand.

The analyst who proposed the use of sand in the determination of solids noted that sand had no effect on the amount of ether extract obtained from whole egg or yolk, and did not seem to accelerate the extraction. The figures which he obtained are given in Table 29.

Table 29.—*Percentage of ether extract obtained when sample is dried with and without sand.*

Sample No.	From solids with sand.		From solids without sand.		Sample No.	From solids with sand.		From solids without sand.	
	A.	B.	A.	B.		A.	B.	A.	B.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Whole egg:					Yolk:				
3972	10.24	10.13	10.23	10.15	4477	28.81	28.89	28.70	28.71
3973	9.32	9.42	9.38	9.39	4478	28.12	28.27	28.07	28.07
3974	9.97	9.64	9.68	9.71	4479	27.37	27.51	27.48	27.29
3975	9.97	10.03	10.04	10.07	4480	27.20	27.12	Lost	27.06
4476	9.95	9.90	9.93	9.90	4481	27.36	27.43	27.35	27.57
Average	9.86		9.85		Average	27.81		27.81	

Effect upon Ether Extract Determination of the Amount of Sample Used for Total Solids Determination.

The difference is so small as to show that either amount may be used, with a slight preference for the larger amount because of greater uniformity (Table 30).

Table 30.—*Percentage of ether extract obtained with varying amounts of the sample.*

Sample No.	Initial of analyst.	Using 2.5± grams.		Using 5.0± grams.	
		A.	B.	A.	B.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
16	B	10.64	10.74	10.72	10.70
	D	10.54	10.46	10.46	10.51
	E	10.51	10.30	10.52	10.41
	H	10.31	10.13	10.44	10.17
	S	10.60	10.70	10.52	10.46
18	B	11.16	11.18	11.15	11.22
	D	11.56	12.78	11.58	11.46
	H	10.88	10.64	9.89	10.81
	S	11.33	11.33	11.14	11.18
1	D	12.36	12.44	12.47	12.45
	E	13.12	12.65	12.85	12.84
	H	13.00	12.60	12.63	12.82
	S	11.63	11.97	12.90	12.11
3	D	11.76	11.71	11.75	11.54
	E	11.57	11.50	11.50	11.47
	H	11.34	11.55	11.46	11.42
	S	11.57	11.42	12.41	11.32
15	D	6.07	5.83	5.84	5.67
	H	5.59	5.59	5.59	5.42
	S	5.94	5.91	5.90	5.88
	Average	10.57		10.53	

Knorr Apparatus vs. Johnson Apparatus for Ether Extract Determination.

As many food laboratories are equipped with the Johnson apparatus but not with the Knorr apparatus, which has almost invariably been recommended for egg work, a comparison of results using the two was made, extracting in all cases for 3 hours.

Table 31.—*Percentage of ether extract obtained by using Knorr apparatus and Johnson apparatus.*

Sample No.	Initial of analyst.	Knorr. Using 2.5± grams.	Knorr. Using 5.0± grams.	Johnson. Using 2.5± grams.	Johnson. Using 5.0± grams.
		Per cent.	Per cent.	Per cent.	Per cent.
16	B	10.64	10.72	10.74	10.70
	D	10.54	10.46	10.46	10.51
	E	10.51	10.52	10.30	10.41
	H	10.31	10.44	10.13	10.17
	S	10.60	10.52	10.70	10.46
18	B	11.16	11.15	11.18	11.22
	D	11.56	11.58	12.78	11.46
	H	10.88	9.89	10.64	10.81
	S	11.33	11.14	11.33	11.18
1	D	12.36	12.47	12.44	12.45
	E	13.12	12.85	12.65	12.84
	H	13.00	12.63	12.60	12.82
	S	11.63	12.90	11.97	12.11
3	D	11.76	11.75	11.71	11.54
	E	11.57	11.50	11.50	11.47
	H	11.34	11.46	11.55	11.42
	S	11.57	12.41	11.42	11.32
15	D	6.07	5.84	5.83	5.67
	H	5.59	5.59	5.59	5.42
	S	5.94	5.90	5.91	5.88
	Average	10.57		10.53	

It is evident that the Johnson apparatus may be substituted for the Knorr apparatus, although the Knorr should always be used if possible.

Effect of Time of Extraction upon the Ether Extract Determination.

Nothing is gained by prolonging the extraction for more than 3 hours, as is shown by the results given in Table 32.

Table 32.—*Percentage of ether extract obtained during varying periods of extraction.*

Sample No.	Extracted 3 hours.	Extracted 16 hours.
	Per cent.	Per cent.
3972	10.24	10.40
	10.13	10.22
	10.23	10.32
	10.15	10.22
Av.	10.19	10.29

DETERMINATION OF ACIDITY OF FAT FROM THE SOLIDS DRIED WITH AND WITHOUT SAND.

Obviously the acidity of the fat is not affected by the presence or absence of sand (Table 33).

TABLE 33.—*Acidity of fat obtained when sample is dried with and without sand.*

Sample No.	From solids with sand. A.	From solids with sand. B.	From solids without sand. A.	From solids without sand. B.
	Cc. N/20 sodium ethylate per gram.	*Cc. N/20 sodium ethylate per gram.*	*Cc. N/20 sodium ethylate per gram.*	*Cc. N/20 sodium ethylate per gram.*
Whole egg:				
3972	1.36	1.54	1.36	1.50
3973	1.32	1.22	1.26	1.30
3974	1.43	1.40	1.36	1.38
3975	1.29	1.26	1.38	1.37
4476	1.52	1.46	1.59	1.59
Average	1.38		1.41	
Yolk:				
4477	1.77	1.81	1.75	1.83
4478	1.77	1.73	1.74	1.79
4479	1.66	1.68	1.71	1.70
4480	1.69	1.62	Lost	1.80
4481	1.55	1.53	1.65	1.64
Average	1.68		1.73	

EFFECT UPON ACIDITY OF THE FAT DETERMINATION OF AMOUNT OF SAMPLE USED.

The results are in favor of the larger amount, as shown by Table 34.

TABLE 34.—*Acidity of fat obtained with varying amounts of sample.*

Sample No.	Initial of analyst.	Using 2.5± grams. A.	Using 2.5± grams. B.	Using 5.0± grams. A.	Using 5.0± grams. B.
		Cc. N/20 sodium ethylate per gram.	*Cc. N/20 sodium ethylate per gram.*	*Cc. N/20 sodium ethylate per gram.*	*Cc. N/20 sodium ethylate per gram.*
16	B	2.09	2.21	2.15	2.22
	D	2.39	1.91	2.08	2.09
	E	2.39	1.91	2.08	1.91
	H	2.61	2.48	2.33	2.19
	S	2.22	2.07	2.17	2.11
18	B	2.09	1.88	1.69	1.67
	D	2.59	2.21	1.80	1.89
	H	2.30	2.06	2.19	1.78
	S	2.21	2.03	1.95	1.97
1	D	2.70	2.54	2.27	1.88
	E	1.85	1.55	1.50	1.52
	H	1.93	1.63	2.09	1.65
	S	1.95	1.92	1.69	1.74
3	D	2.91	2.43	2.21	1.93
	E	1.72	1.74	1.51	1.52
	H	2.13	1.52	2.05	1.70
	S	1.71	1.74	1.67	1.63
15	D	4.48	2.78	3.34	2.47
	H	2.71	2.35	2.71	1.90
	S	1.81	1.79	1.94	1.81
	Average	2.21		1.98	

EFFECT UPON THE ACIDITY OF THE FAT DETERMINATION OF USING THE KNORR OR JOHNSON APPARATUS.

Table 35 shows the effect upon the acidity of the fat determination of using the Knorr apparatus and Johnson apparatus.

TABLE 35.—*Acidity of fat obtained by using the Knorr apparatus or Johnson apparatus.*

Sample No.	Initial of analyst.	Knorr. Using 2.5± grams.	Knorr. Using 5.0± grams.	Johnson. Using 2.5± grams.	Johnson. Using 5.0± grams.
		Cc. N/20 sodium ethylate per gram.	*Cc. N/20 sodium ethylate per gram.*	*Cc. N/20 sodium ethylate per gram.*	*Cc. N/20 sodium ethylate per gram.*
16	B	2.09	2.15	2.21	2.22
	D	2.95	2.18	2.13	2.09
	E	2.39	2.08	1.91	1.91
	H	2.61	2.33	2.48	2.19
	S	2.22	2.17	2.07	2.11
18	B	2.09	1.69	1.88	1.67
	D	2.59	1.80	2.21	1.89
	H	2.30	2.19	2.06	1.78
	S	2.21	1.95	2.03	1.97
1	D	2.70	2.27	2.54	1.88
	E	1.85	1.50	1.55	1.52
	H	1.93	2.09	1.63	1.65
	S	1.95	1.69	1.92	1.74
3	D	2.91	2.21	2.43	1.93
	E	1.72	1.51	1.74	1.52
	H	2.13	2.05	1.52	1.70
	S	1.71	1.67	1.74	1.63
15	D	4.48	3.34	2.78	2.47
	H	2.71	2.71	2.35	1.90
	S	1.81	1.94	1.79	1.81
	Average	2.22		1.96	

USE OF DUBOSCQ AND SCHREINER COLORIMETERS IN THE NESSLERIZATION METHOD FOR AMMONIA NITROGEN.

As many food laboratories are equipped with Schreiner colorimeters and not with Duboscq instruments which have always been recommended for this work, a series of comparative tests was made with the two instruments, using the same solutions in both instruments. The results are given in Table 36.

TABLE 36.—*Ammonia nitrogen obtained by use of Duboscq and Schreiner colorimeters in the nesslerization method.*

Sample No.	Initial of analyst.	Ammonia nitrogen.			Sample No.	Initial of analyst.	Ammonia nitrogen.		
		Duboscq.	Schreiner.	Titration.			Duboscq.	Schreiner.	Titration.
		Mg. per 100 grams.	*Mg. per 100 grams.*	*Mg. per 100 grams.*			*Mg. per 100 grams.*	*Mg. per 100 grams.*	*Mg. per 100 grams.*
45	B	1.5	1.2	2.0	66	H	1.8	1.4	2.9
46	B	1.6	1.3	1.9		S	3.0	2.8	3.1
47	B	1.9	1.5	2.2	67	E	2.0	2.0	2.1
48	B	2.1	1.8	2.8		H	2.3	2.5	2.5
51	B	4.6	3.9	4.5		S	2.4	2.2	2.2
60	D	3.1	2.7	3.0	76	E	2.3	2.3	2.4
	E	2.3	2.2	2.6		H	2.7	2.1	2.9
	H	2.6	1.8	3.0		S	2.7	2.3	2.8
61	D	2.9	2.4	2.8	77	E	7.0	6.8	7.5
	E	2.4	2.5	2.6		H	8.0	6.6	6.6
	H	3.0	2.4	3.0		S	8.2	8.5	8.1
62	D	6.3	6.0	6.9	68	E	6.5	6.1	4.2
	E	6.1	6.7	6.5		H	3.7	2.8	4.9
	H	6.5	5.9	6.8		S	5.5	5.3	4.5
63	D	9.9	8.2	7.6	69	E	6.5	6.7	4.4
	E	7.0	8.0	8.0		H	4.5	4.5	5.0
	H	7.8	8.2	8.7		S	5.7	4.9	4.7
74	D	2.3	2.1	2.6	70	E	2.2	2.1	2.1
	E	2.1	2.2	2.4		H	2.4	1.5	2.1
	H	2.0	1.4	2.7		S	2.9	2.4	2.4
75	D	2.1	2.0	2.8	71	E	2.5	2.4	2.1
	E	2.1	2.0	2.9		H	2.4	1.8	2.5
	H	2.3	1.5	2.3		S	2.4	2.1	2.4
64	E	2.4	2.4	2.2	72	E	2.7	2.7	2.5
	H	2.3	2.1	2.3		H	4.5	3.1	2.8
	S	2.4	2.0	2.8		S	2.7	2.3	2.8
65	E	2.4	2.3	2.3	73	E	3.3	3.2	2.7
	H	1.9	1.6	2.8		H	2.0	1.4	3.2
	S	2.8	2.3	2.6		S	3.0	3.6	3.1
66	E	2.7	2.7	3.0					

From Table 36 it is evident that the Schreiner instrument may not be substituted for the Duboscq colorimeter, since it gives results which are in the majority of cases decidedly lower than those obtained with the Duboscq instrument. By comparing the nesslerization results with the titration results, it will be seen that the results with the Duboscq colorimeter are too low and that the results with the Schreiner, which are still lower, are decidedly inaccurate.

NESSLERIZATION METHOD FOR AMMONIA NITROGEN.

Dissatisfaction with the nesslerization method for the determination of ammonia nitrogen was expressed by the chemists throughout the cooperative work, not only because of the lack of uniformity of results, but also because of mechanical difficulties in the method. Much trouble was experienced with foaming. At first this was overcome to a large extent by adding a few cubic centimeters of amyl alcohol, but this method has the disadvantage that the amyl alcohol, due to its volatility, often must be added more than once during the aeration, and also it has a tendency to give a slight blank reading. Later very heavy cylinder oil was used successfully to prevent foaming. Recently one of the analysts reported in connection with some determinations made on samples subsequent to the cooperative work that the nesslerization method caused difficulty, although the reagents used were the same as those which had given satisfactory results a few months before. He considers the method too uncertain on account of the foaming and sometimes also turbidity to meet with general approval.

The consensus of opinion of those who participated in the work here reported is that while the nesslerization method for ammonia nitrogen in frozen-egg products may, because of the shorter time which it consumes, be of value, it is not nearly as accurate as the titration method, which is preferable where absolutely dependable results are required, as, for example, in analyses where court action may be involved. If the nesslerization method is used for this purpose it should be run in triplicate and the average result employed.

Strength of Alumina Cream to Be Used in the Reducing Sugar Determination.

During the course of the work the question arose as to whether, if alumina cream was kept in a large container and was not always shaken to a homogeneous mixture before a portion was removed for use, the results would be affected by the use of cream of varying concentrations. To decide this, alumina cream of regular strength was prepared, and it was used as such and also after dilution with varying amounts of water. The results are shown in Table 37.

Table 37.—*Reducing sugar obtained with alumina cream of varying strengths.*

Initial of analyst.	100 cc. alumina cream, 0 cc. water.	75 cc. alumina cream, 25 cc. water.	50 cc. alumina cream, 50 cc. water.	25 cc. alumina cream, 75 cc. water.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
B	0.31	0.30	0.30	0.29
B	.31	.30	.31	.32
D	.38	.36	.37	.37
D	.36	.36	.38	.36
E	.33	....	.32	....
E	.16	....	.18	....
E	.43	....	.44	....
H	.35	.36	.34	.35
S	.32	.33	.34	.32

These tabulated results prove conclusively that the concentration of the alumina cream has no influence.

Choice Between Sulphuric and Hydrochloric Acids in the Detection of Indol and Skatol.

Experiments proved that sulphuric acid is preferable, because it gives more distinct colorations.

METHODS ADOPTED.

Frozen Eggs.

TAKING OF SAMPLES.

When possible, frozen egg samples consist of original unopened packages, comprising representative containers of the product in any individual shipment. Take enough containers to represent fairly a whole shipment, and send all samples to the laboratories in the quickest possible way. When transported by common carriers, pack the samples so as to prevent thawing, and take every precaution to prevent delay in transit. Deliver the samples to the bacteriologist immediately upon arrival at the laboratory, and examine no sample which does not arrive in a frozen condition. If the material is slightly melted around the circumference, the subsamples for bacteriological and chemical examination must be withdrawn from the portion which is still frozen.

When samples are opened, the bacteriologist, chemist, and microscopist all are present, and, in case of official samples, they initial and date seals and cans for identification in the regular manner. To preclude all possibility of a claim of contamination during sampling, the bacteriologist withdraws subsamples first when a container is opened. The chemist then withdraws subsamples, and the remainder is turned over to the microscopist. Each analyst gives a receipt to the one from whom the container is received in the case of official samples.

SUBSAMPLES FOR BACTERIOLOGICAL EXAMINATION.

Take subsamples for bacteriological examination by means of sterilized utensils, and place them in sterile containers, which are then immediately placed on ice. Take two subsamples of at least 100 grams each from every can of egg material, one for immediate examination, and one to be placed as quickly as possible in cold storage at approximately 0° F., for a later check examination, if necessary.

For withdrawing subsamples it will be found convenient to use a sterile butter sampler long enough to insure the removal of a core of frozen material from the top to the bottom of the container, after the surface layer of the frozen material has been removed with a sterilized instrument (chisel). If the sample is frozen very solid it may be found necessary to use a brace and long-shanked bit or shipbuilder's auger, and to collect the shavings for the sample. Cores should be taken midway between the center and circumference, from at least three widely separated parts of the container, to form a composite sample.

Thoroughly sterilize the butter sampler or bit before use by flaming over a Bunsen burner or alcohol lamp, after immersion in alcohol.

If it is necessary to use a spoon to collect the chips made by a bit, it should be sterilized in like manner. Wipe all utensils thoroughly clean with a cloth before each sterilization. Thoroughly cleansed Mason jars, which have been sterilized in the autoclave with the rubber rings and covers in place, make convenient containers for subsamples.

The bacteriologist records the general condition of all samples at the time of sampling, specifying the temperature, appearance, color, and odor.

SUBSAMPLES FOR CHEMICAL EXAMINATION.

The two chemical subsamples are taken in the same way as the bacteriological subsamples, except that sterile instruments and containers need not be used, and at least 1 pound of material is collected for each subsample. One of these should be placed in cold storage immediately at approximately 0° F.

SUBSAMPLES FOR PHYSICAL AND MICROSCOPICAL EXAMINATION.

These consist of the entire contents of each container, after the bacteriological and chemical subsamples have been removed.

LIQUID EGG.

Thoroughly mix liquid egg samples with a sterilized utensil, such as a long-handled dipper which has been immersed, including the handle, in alcohol and flamed, after which subsamples are withdrawn for examination. Place the subsamples for bacteriological examination in sterilized containers. Keep a record of the general condition at the time of sampling, specifying the temperature, appearance, color, and odor.

SHELL EGGS.[1]

WHOLE EGG.

Clean each egg[2] with brush, soap, and water, and immerse for 10 minutes in a 1:500 mercuric chlorid solution. Transfer with sterile crucible tongs to a small conical graduate or other convenient holder, acute pole uppermost. Remove the mercuric chlorid and dry the egg by pouring over it first alcohol and then ether. Scorch the acute pole to kill spores that may remain. Immediately remove the egg from the graduate, holding it near the blunt pole, turning the acute pole down. The hands of the operator should have been thoroughly greased with vaseline to avoid contamination by bacteria that might rub off during the handling of the eggs. Hold the

[1] These methods are included because they were used in the preparation and examination of samples in the laboratories.

[2] Adaptation of method of Bushnell and Maurer, Kansas Agr. Coll. Bul. 201.

egg over the sterile container [1] which is to receive its contents, and with sharp, stout forceps, which have been sterilized in the flame, make a hole of sufficient size to allow the contents of the egg to drop into the container. Contamination from above is prevented by holding the egg with the acute pole down and making the stab from below.

In this manner introduce the contents of the desired number of eggs into the container. Then thoroughly mix these eggs with a sterilized electric stirrer, like those used at soda fountains to mix eggs.

SEPARATED YOLK AND WHITE.

Clean each egg with brush, soap, and water, and immerse for 10 minutes in 1:500 mercuric chlorid solution. Transfer with sterile crucible tongs to a small conical graduate or other convenient holder, acute pole uppermost. Remove the mercuric chlorid, and dry the egg by pouring over it first alcohol and then ether. Scorch the acute pole to kill spores that might remain. Immediately remove the egg from the graduate, holding it near the blunt pole and turning the acute pole down. The hands of the operator should have been thoroughly greased with vaseline to avoid contamination by bacteria that might rub off during the handling of the eggs. With sharp, stout forceps which have been sterilized in the flame, make a hole about ½ centimeter in diameter in the acute pole. Contamination from above is prevented by holding the egg with the acute pole down and making the stab from below. Flame briskly the shell around the hole and put the egg, with the acute pole down, upon the flamed neck of a sterilized Erlenmeyer flask. Now heat the blunt end of the egg with a Bunsen flame, keeping a close watch on the hole. The heating expands the air in the air space, which expels the white of the egg. As soon as the yolk appears in the hole, interrupt the heating and tilt the egg from one side to the other to allow all of the albumen to run out. Then hold the egg over another sterilized container, and with a sterile platinum needle puncture the vitelline membrane.

In this way collect the whites of the desired number of eggs in one container and the yolks in another. Finally thoroughly mix the whites with a sterile electric stirrer. The yolks are treated in like manner.

BACTERIOLOGICAL EXAMINATION.

Start the bacteriological examination immediately after the taking of subsamples, all determinations being made on the gram basis. After melting a subsample by partially immersing the container in

[1] A thoroughly cleaned Mason jar which has been sterilized in the autoclave with rubber ring and cover in place makes a good container.

water at 40° C., thoroughly mix the material with a sterilized electric stirrer of the type commonly used at soda fountains for mixing eggs. One with a detachable plunger, which can be removed, dipped in alcohol and flamed, is best. Examine this mixed composite sample by the following methods:

ENUMERATION OF VIABLE BACTERIA.

Into a tared, sterile, glass-stoppered Erlenmeyer flask of 60 to 100 cc. capacity, weigh approximately 5 grams of the mixed composite sample to the nearest hundredth of a gram, and dilute with 9 cc. of sterile physiological salt solution (0.85 per cent sodium chlorid) for each gram of egg. Add about 2 grams of sterile glass beads or broken glass. Shake thoroughly until the mixture is homogeneous. Further dilutions are made in the regular way by transferring 1.0 cc. of the mixture to 9 cc. or 99 cc. dilution bottles of sterile physiological salt solution in the customary manner. From the appropriate dilutions prepare a series of plates with standard nutrient agar for counting after incubation at not less than 19° C. or more than 21° C. for 5 days. Perform all of these operations in duplicate.

No count of bacteria is official unless based upon duplicate plates which agree closely and have between 30 and 300 colonies upon them when counted with a lens magnifying 3½ diameters, or what opticians call a three and one-half X lens. In case it is doubtful whether certain objects are colonies or dirt specks, examine them with a compound microscope.

ENUMERATION OF B. COLI.

Inoculate lactose broth fermentation tubes, in duplicate, with appropriate dilutions of the sample, and make a quantitative determination of the presence of members of the *B. coli* group.[1]

ENUMERATION OF TOTAL BACTERIA.

In a tared clean flask of about 50 cc. capacity, weigh approximately 5 grams of the well-mixed sample to the nearest hundredth of a gram, and dilute with twice the amount of physiological salt solution. Add sterile glass beads or broken glass, and mix thoroughly till homogeneous. Transfer a 0.01 cc. portion of this mixture to a microscopic slide by means of a capillary pipette of such bore that 0.01 cc. occupies from 1.2 to 2 centimeters, and the tip of which pipette has been ground to a truncated cone. Lay the slide on a piece of black paper upon which a square, 2 centimeters to a side, has been ruled with white ink. By means of a heavy platinum needle, bent into the shape of a hockey stick, spread the liquid evenly over the square within the white lines. A drop of distilled

[1] Standard Methods of Water Analysis of the American Public Health Association.

water may be added, if necessary, to obtain an even distribution. Dry in the air on a level surface. Make three such slides from each subsample.

Immerse the slides carrying the dried egg films in xylol or benzol for 1 minute. Again dry, and place in 1 per cent carbolic methylene blue for from 10 to 20 minutes. The object is to stain the bacteria deeply, and to stain fat, débris, and background as lightly as possible. To do this, wash off the excess of stain in water, and immerse in 50 to 60 per cent alcohol until only a faint blue is visible. This decolorizing is quickly done. Failure to decolorize is followed by serious errors in results.

Dry, and examine with the microscope, counting 20 fields along the diagonals of each slide.

A desirable optical combination to employ is that which is used in the direct microscopic examination of milk. The microscope should have an oil immersion objective and an ocular giving the field desired, and should be fitted with a mechanical stage. To standardize the microscope, place upon the stage a stage micrometer, and on the diaphragm of the ocular place an eyepiece micrometer, with a circular ruling, 8 mm. in diameter, and divided into quadrants. Adjust the draw tube until the inner circle of the eyepiece micrometer has a diameter of 0.146 mm. Record the necessary adjustment of the draw tube. By this adjustment, the inner circle will cover 1/7,200,000 cc. of the undiluted egg, giving a factor of 7,200,000. This means that the number of bacteria in a single field should be multiplied by 7,200,000, or, if 60 fields are counted, the total number should be multiplied by 120,000, to obtain the number of bacteria in 1 cc. of the original egg material. If any variation from this procedure is used, the factor must be calculated.

Chemical Examination.[1]

Start the chemical examination immediately after the taking of subsamples, and make all determinations in duplicate. Thaw the subsamples by partially immersing the containers in warm water, the temperature of which should not be above 50° C. Then thoroughly mix them, preferably with an electric stirrer. In the absence of such an instrument in the laboratory, the mixing may be quite satisfactorily accomplished by sucking the melted subsample several times through a Gooch crucible containing no asbestos, using very moderate suction. Examine this mixed composite sample by the following methods:

TOTAL SOLIDS.

Weigh approximately 5 grams of the sample into a tared lead dish of $2\frac{1}{2}$ to 3 inches diameter, and dry in a vacuum of not less than 25 inches at 55° C., until there is no further loss in weight. This drying

[1] The analytical methods described were very largely devised or adapted to egg analysis by N. Hendrickson, formerly of the Food Research Laboratory.

usually requires about 4 hours. It is recommended that weighings be made at the end of 3½ hours of drying, and thereafter at intervals of about 30 minutes. Weigh to three decimal places. There is an appreciable gain in weight after the minimum has been reached. Express the results as per cent on the wet basis.

ETHER, EXTRACT.

Extract the dry residue from the determination of solids with absolute ether, preferably in a Knorr apparatus, but if this is not available, in a Johnson extractor. Cut through the sides of the lead dish containing the solids at four equidistant points. Place the dish upon a fat-free filter paper. Flatten down the sides of the dish. Place another fat-free filter paper on top of the flattened dish, and roll the papers and dish into a cylinder which will fit the extraction tube fairly snugly. In making the cylinder, turn in the ends in such a way as to prevent solid particles from dropping into the extraction flask. Place the cylinder in the extraction tube without any asbestos plug below it. If the extractor is working rapidly, three hours is sufficient to insure a proper extraction.

Distill off the ether from the extraction flask, and dry the extract for one hour at 55° C., in a vacuum of not less than 25 inches. Weigh to three decimal places. Express the results as per cent on the wet basis.

The ether used should not contain any alcohol or water, as a higher result is obtained when either is present. It is, therefore, understood that ether freshly distilled from sodium will be used.

ACIDITY OF THE FAT.

Dissolve the fat obtained in the determination of ether extract in 50 cc. of neutral benzol to which has been added 2 drops of phenolphthalein indicator. Titrate with N/20 sodium ethylate. Express the results as the number of cubic centimeters of N/20 sodium ethylate required to neutralize 1 gram of fat.

AMMONIA NITROGEN.

The titration method is an adaptation of Folin's method for the determination of ammonia in urine.[1] It consists essentially in making the sample alkaline, removing the liberated ammonia by aeration, and catching it in a measured quantity of standardized acid. The excess acid is then titrated.

The apparatus consists of the following: (1) A wash bottle containing dilute sulphuric acid (about 35 per cent) to remove any ammonia that may be present in the air entering the system. (2) Some form of trap to prevent sulphuric acid being carried over mechanically. (3) An aerating cylinder about 50 mm. in diameter and 350 mm.

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[1] Zeit. physiol. Chem. (1902), 37: 161.

high, fitted with a 2-hole rubber stopper carrying a right-angle air-inlet tube, open at the bottom and extending to within ½ inch of the bottom of the cylinder, and a trap containing either a cotton or glass wool plug to prevent any liquid from being carried over mechanically. (4) A wide-mouthed 8-ounce bottle fitted with a delivery tube coming from the trap on the aerating cylinder. It is not essential that the special ammonia absorption tubes be used. An ordinary glass tube with a small bulb blown on the end through which a few holes are punctured answers very well. The method of making these is given by Folin and Farmer.[1] (5) A means of passing air through the system. This is best done by a pump which will furnish a blast with a pressure of 10 pounds per square inch and which discharges into a tank of sufficient size to compensate for the pulsations of the pump and to deliver a steady blast. Suction may be used, but it is not recommended. Each of the first four parts enumerated is fitted with a 2-hole rubber stopper, and all are connected by glass tubes of suitable shape and length to permit the proper passage of air through the apparatus. The tube leading into the acid wash bottle should contain a stop cock for regulating the air supply.

Weigh approximately 25 grams of sample in a convenient container. Pour as much as possible of this material into the aeration cylinder, and transfer the remainder by means of four 25 cc. portions of ammonia-free water, stirring each time with a rubber-tipped glass rod to remove any egg adhering to the sides of the weighing vessel. Add 75 cc. of alcohol, mix well, let stand for 15 minutes. Add approximately 1 gram of sodium fluorid, 2 cc. of 50 per cent potassium carbonate solution, and 1 cc. of kerosene. Connect the apparatus, and aerate into the receiving bottle, which should contain 10 cc. of N/50 sulphuric acid, 2 drops of methyl red indicator (saturated solution in 95 per cent alcohol), and about 75 cc. of ammonia-free water. The aeration should be carried on for 4 hours, or as long as necessary to remove all of the ammonia, using as rapid a current of air as possible. Titrate the excess of acid with N/50 sodium hydroxid (free from carbon dioxid). Express the results obtained as milligrams of ammonia nitrogen per 100 grams of sample on the wet basis. If there is insufficient time to complete the determination, the sample may be left over night in the cylinder with the alcohol and sodium fluorid added. The potassium carbonate, of course, should not be added until ready to proceed. If the sample has a bad odor it may be necessary to use more than 10 cc. of N/50 sulphuric acid.

It is essential that a blank experiment be run to determine the percentage recovery of ammonia, using a known amount of pure

[1] J. Biol. Chem. (1912), 11: 496.

ammonium sulphate [1] (containing about 3 mg. of nitrogen) and 25 cc. of water, instead of the egg. The recovery should be over 95 per cent. It is also essential to run blank experiments with the reagents and water used.

The nesslerization method is an adaptation of the micro-method of Folin and Macallum for the determination of ammonia in urine.[2] The essential features of the method consist of rendering a small sample alkaline, removing the liberated ammonia by aeration, and catching it in dilute sulphuric acid. This is then nesslerized, and the ammonia determined quantitatively by comparing the intensity of the color with a known standard in a Duboscq colorimeter.

The apparatus employed is as follows: (1) An ordinary acid bottle, fitted with a 2-hole rubber stopper, and containing from 200 to 300 cc. of 35 per cent sulphuric acid, to serve as a wash bottle for removing any ammonia that may be present in the air which passes through the system. (2) A 10 by $1\frac{1}{8}$ inch test tube of strong glass connected to the wash bottle, to serve as a trap to remove any spray of dilute acid. (3) A small Kjeldahl flask of about 125 cc. capacity for holding the sample. (4) A 10 by $1\frac{1}{8}$ inch test tube, to serve as a trap to catch any foam which may be formed in the sample and carried over mechanically. (5) A 100 cc. volumetric sugar flask containing 2 cc. of approximately N/20 sulphuric acid and about 20 cc. of ammonia-free water. (6) A means of passing air through the system, like that described for the titration method (p. 91). Blast at 10 pounds pressure is preferred; suction may be used. Each of the first five parts enumerated is fitted with a 2-hole rubber stopper, and all are connected by glass tubes of suitable shape and length to permit the proper passage of air through the apparatus. The tube leading into the acid wash bottle should contain a stop cock for regulating the air supply. It is essential that the tube leading into the 100 cc. graduated flask receiving the volatile ammonia be bulb-shaped on the end and perforated with small holes to insure thorough dispersion.

Weigh approximately 3 grams of sample on a watch glass and add a few drops of water at a time, mixing into a homogeneous mass with a rubber-tipped glass rod, until about 3 cc. of water have been added. Then wash into the Kjeldahl flask with about 10 cc. of ammonia-free water. Add 6 cc. of a solution containing 10 per cent of sodium carbonate and 15 per cent of potassium oxalate. Add enough very heavy cylinder oil to make a layer over the liquid. Pass through this mixture a current of air of sufficient strength to cause a slight spray in the receiving flask, which contains about 20 cc. of ammonia-free water made acid with 2 cc. of approximately N/20 sulphuric acid. Aerate for 1 hour and dilute the liquid in the flask

[1] For method of preparing pure ammonium sulphate, see Folin and Farmer, J. Biol. Chem. (1912), 11: 496.
[2] J. Biol. Chem. (1912), 11: 523.

nearly to the 100 cc. mark with ammonia-free water. Add 2 cc. of Nessler solution, fill the flask to the mark with ammonia-free water. Close the flask with a thoroughly washed rubber stopper, and shake well. Compare the color in a Duboscq colorimeter [1] with that of a known standard made up at the same time, and containing 2 cc. of approximately N/20 sulphuric acid. Express the results as milligrams of ammonia nitrogen per 100 grams of sample on the wet basis.

It is essential that a blank experiment be run, using a known amount of pure ammonium sulphate (containing about 0.3 mg. of nitrogen) and 25 cc. of ammonia-free water, instead of the egg material. Such an experiment should show over 95 per cent recovery. It is also essential to run blank experiments with the reagents and water used.

This method while more rapid is not as accurate as the titration method. If it is employed for samples where legal action may be involved, it should be run in triplicate, and the average of the three determinations used.

Phosphotungstic acid method.—Weigh 5 grams of well-mixed sample in a tared 100 cc. glass-stoppered Erlenmeyer flask. Add 45 cc. of phosphotungstic acid solution made up as follows: Water, 420 cc.; 1 per cent sulphuric acid, 10 cc.; 20 per cent phosphotungstic acid, 20 cc. Shake well. Let stand 5 minutes, and filter through a folded ammonia-free filter paper. Transfer to an aeration cylinder 10 cc. of filtrate, which corresponds to 1 gram of sample; add 2 drops of white petroleum oil, and 1 cc. of 10 per cent solution of sodium carbonate. Aerate strongly for ½ hour into 3 cc. of 1 per cent sulphuric acid. The same chain of apparatus as that described for the nesslerization method (p. 92) should be used. Nesslerize with 0.25 cc. of a Nessler solution made with mercuric iodid, dilute to 10 cc. with ammonia-free water, and compare with a standard prepared with 0.03 mg. of nitrogen in the form of ammonium sulphate in 10 cc. volume.

If a heavy red precipitate forms on adding Nessler solution, add just enough 5 per cent acetic acid to dissolve it, dilute to about 45 cc., again add Nessler solution, and make up to 50 cc. Make the necessary change in the calculation for the greater dilution. Express the results as milligrams of ammonia nitrogen per 100 grams of sample on the wet basis.

This method is good for rapid and approximately accurate work, but should not be used for samples where legal action may be involved.

REDUCING SUGAR.

Wash 25 grams of sample into a 200 cc. graduated flask with 75 cc. of water. Make slightly acid by adding 2 cc. of 5 per cent acetic acid for white or whole egg and 1 cc. for yolk. Mix, and immerse the flask in boiling water until the egg material is thoroughly coagulated. This

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[1] The Schreiner instrument gives results which are too low.

requires about 15 minutes. Cool to room temperature, and make up to the mark with washed alumina cream. The sample is then shaken vigorously for 1 minute, is allowed to stand about 5 minutes, and then shaken for 1 minute. Filter through a dry folded filter, and determine the reducing sugar in 50 cc. of the filtrate by the Munson and Walker method. Calculate as dextrose, and express the results as per cent on the wet basis.

The washed alumina cream is prepared by washing ordinary alumina cream five times by decantation, using enough water so that at least half of the total volume may be syphoned off each time.

On account of the volume occupied by the precipitate the results are a trifle high. This error amounts to about 1.4 per cent for white, 3.3 per cent for whole egg, and 7 per cent for yolk. It is not customary to correct for this.

INDOL AND SKATOL.

Dilute a 200 cc. portion of sample with 500 cc. of water, acidified with 40 cc. of 5 per cent acetic acid for white or whole egg, and with 20 cc. for yolk, coagulate in boiling water or live steam, and filter. Steam distill the filtrate as rapidly as possible. Extract the distillate (approximately 300 cc.) with ether in a separatory funnel. To the ether extract add about 3 cc. of water, and evaporate before an electric fan until the smell of ether has almost but not entirely disappeared. A trace of ether does not affect the result. Add 10 cc. of water, filter, and apply the vanillin test to the filtrate.

Vanillin test.—To 5 cc. of the solution to be tested add 5 drops of a 5 per cent solution of vanillin in 95 per cent alcohol and concentrated sulphuric acid. The acid should be added in the proportion of 2 cc. for each 5 cc. of solution being tested. If indol is present, an orange color, soluble in chloroform, amyl acetate, or amyl valerianate, will be formed. If skatol is present, a deep red to violet color, readily soluble in chloroform, amyl acetate, or amyl valerianate, will be formed.[1]

As confirmatory tests, if needed, the following are suggested:

P-Dimethylaminobenzaldehyde test.—To the solution to be tested add 1 cc. of a solution consisting of 4 parts of para-dimethylaminobenzaldehyde, 380 parts of absolute alcohol, and 80 parts of concentrated hydrochloric acid, in such a way as to form two liquid layers.[2] If indol is present a purplish red color will be formed.

Dimethylaniline test.—To 5 cc. of the test solution add 5 drops of dimethylaniline and 4 cc. of concentrated sulphuric acid. If skatol is present, a deep red violet coloration is formed.[3]

PRESERVATIVES.

Formaldehyde.—The test may be made exactly as in milk.[4]

Boric acid.—Make the test as in milk.[5]

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[1] J. Biol. Chem. (1916), 24: 528.
[2] Zeit. physiol. chem. (1906), 42: 25.
[3] J. Biol. Chem. (1916), 24: 527.
[4] Leach, Food Inspection and Analysis, 3d ed., page 268.
[5] Leach, Food Inspection and Analysis, 3d ed., page 182.

Salicylic acid.—Use the method for the detection of salicylic acid in preserved eggs.[1]

MISCELLANEOUS CHEMICAL TESTS.

The chemical tests described are those which up to the present time have been found most useful in detecting the presence of decomposed egg material. With advances in knowledge it is probable that these will be supplemented and possibly displaced by new and even better methods. The following methods, upon which some work has already been done, seem to offer possibilities:

Inorganic phosphoric acid.—R. M. Chapin and W. C. Powick have discussed "An Improved Method for the Estimation of Inorganic Phosphoric Acid in Certain Tissues and Food Products," in the Journal of Biological Chemistry (1915), volume 20, number 2, page 97.

Separation and quantitative determination of the lower alkylamines in the presence of ammonia.—A method for this separation and determination has been published by F. C. Weber and J. B. Wilson in the Journal of Biological Chemistry (1918), volume 35, number 2, page 385.

Catalase.—Tests for this determination are discussed by Rullman in Centralblatt für Bakteriologie, Parasitenkunde und Infectionskrankheiten. II Albteilung (1915), volume 45, page 219, and by M. E. Pennington and H. C. Robertson, jr., in U. S. Department of Agriculture, Bureau of Chemistry Circular 104.

Determination of degree of putrefaction.—F. W. Foreman and G. S. Graham-Smith have reported their method in the Journal of Hygiene (1917), volume 16, page 109.

PHYSICAL AND MICROSCOPICAL EXAMINATION.

Note the odor of frozen egg products while the product is frozen and again after thawing. For this purpose remove a small amount from the can and immediately thaw it. Allow the remainder of the contents of the can to thaw in running cold water, which takes about 12 hours for a 30-pound can. Examine the sample for mold, embryos, eggshells, dirt, larvæ, and other foreign material by the following methods:

PHYSICAL.

Note the odor of the eggs. Good eggs have a characteristic eggy odor, which must be distinguished from a sour, a musty, and a rotten odor of bad eggs. Then make a physical examination to detect the presence of mold, embryos, eggshells, dirt, larvæ, and any foreign material, as follows:

Dip out a small amount into a large, flat pan, the one most satisfactory being white enamel, 2 inches deep and measuring 12 by 17 inches. Add enough water to the egg to make a thin mixture, about one-

[1] Chem. Abs. (1914), 8: 3331.

half inch deep; separate any masses present by the fingers or forceps until the whole is a homogeneous mixture. By tilting the pan back and forth any thickened portions or black specks can be detected. These thickened portions of albumen and yolk, which may or may not be discolored, generally contain mold. Remove any suspicious pieces, and examine microscopically. If embryos are present they can be detected by a dark spot, which is the pigment in the eye. After carefully examining a panful in this manner, strain it through a sieve, usually one of the ordinary household type, 12 inches in diameter, with about 1½ mm. mesh (or 16 or 20 meshes to the inch). Wash through the sieve all of the egg which will go through easily without rubbing. Search what remains on the sieve for mold, embryos, dirt, etc. The entire sample should be examined in this manner. Express results as number of each per 30 pounds of material.

MICROSCOPICAL.

Any pieces picked out of the egg as being suspicious must be examined microscopically. If mold is present this examination will show the mycelium, which may be colorless or dark. Often spores are present. To detect the mycelium it is necessary to make a thin mount through which the light readily passes. The lighting must be carefully adjusted, however, as the mycelium is generally about the color of the egg. This requires only a small amount of each piece. The remainder, as well as the embryos and foreign material, should be preserved in 5 per cent formalin for court exhibit. It is unnecessary to make a microscopical examination for embryos, as those found are usually of from three to five days' development. At this age they are well formed and easily recognized macroscopically.

The analyst must become familiar with the appearance of various kinds of inedible eggs. This can easily be accomplished by obtaining rejects from a candling establishment and breaking them out. The spot eggs found in frozen eggs are heavy spots where the yolk is thickened and of a whitish appearance, or moldy spots, or spot eggs containing embryos. White rots can not be determined by this examination, as they are too intimately mixed with the whole mass.

SUMMARY.

Analytical results for eggs of the same quality agree very closely, no matter whether the eggs are produced and examined in Washington, Philadelphia, New York, Chicago, or San Francisco. When carefully followed, the analytical methods described in this bulletin will give concordant results in the hands of a number of analysts. A formula has been devised which will separate into edible and inedible groups samples of liquid or frozen white, whole egg, yolky mixture, and yolk prepared from either fresh eggs or storage eggs. A formula for sugared yolk is also proposed.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 847

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER August 9, 1920

ROUNDHEADED APPLE-TREE BORER[1]: ITS LIFE HISTORY AND CONTROL.

By Fred E. Brooks, *Entomologist, Deciduous Fruit Insect Investigations.*

CONTENTS.

INTRODUCTION.

In the spring of 1911 a field station of the Bureau of Entomology was established at French Creek, W. Va., and a study begun of the roundheaded apple-tree borer in connection with a general project on boring insects attacking deciduous fruit trees. The work was under the direction of Dr. A. L. Quaintance and was placed in charge of the writer, with whom was associated, in 1911 and 1912, E. B. Blakeslee, of the Bureau of Entomology. During the summers of 1915, 1916, and 1917 C. R. Cutright was employed temporarily to assist with the investigation.

The field station is located in a hilly, partly wooded region where small orchards, wild seedling apple trees, and native host trees of the borer abound and where the insect itself is plentiful. For rearing purposes and the testing of control measures, 1,000 3-year-old apple trees, of the varieties known as King, Grimes, and York Imperial, were planted in the adjacent locality of Elkins, W. Va., on land leased for the purpose. In addition to the work at the two points mentioned, rearing and life-history studies were conducted at Pickens, Weston, and Great Cacapon, W. Va., and at Demorest, Ga.,

[1] *Saperda candida* Fabr.; order Coleoptera, family Cerambycidae.

Biltmore, N. C., Winthrop, Me., and Munising, Mich. First-hand observations on the species were made also in many other localities and more or less original data obtained therefrom. The studies were continued over the period 1911 to 1918.

HISTORY.

The roundheaded apple-tree borer was first described by J. C. Fabricius in 1787 (1)[1] as *Saperda candida.* In 1824 it was redescribed by Thomas Say (2) as *Saperda bivittata*, and by this name it was commonly referred to by Harris, Fitch, Walsh, and other early American writers on economic entomology. From 1875 to 1885 Riley, Lintner, and others recognized the priority of Fabricius's name, and since that time the species has been rightfully designated *Saperda candida.*

The insect is native to North America and originally fed upon and bred within a limited number of forest trees and shrubs belonging to the family Rosaceae. When cultivated orchards of apple, pear, and quince began to be established in the eastern part of the United States the borer soon found its way from the forests into the orchards and did much damage to valuable fruit trees. There are many records of serious injury in New York and throughout the New England States, beginning as early as 1825. Apple trees seem to have suffered most; in some cases entire orchards were destroyed, and the loss of 50 per cent of the trees was not unusual. Felt and Joutel (6) cite numerous historical references showing the widespread and destructive nature of the insect in the days of pioneer orcharding in this country. In more recent times, as the orcharding interests of the country have developed, losses from this insect have increased rather than diminished. At the present time it is an orchard pest of primary importance throughout a great portion of the apple-growing region east of the Rocky Mountains.

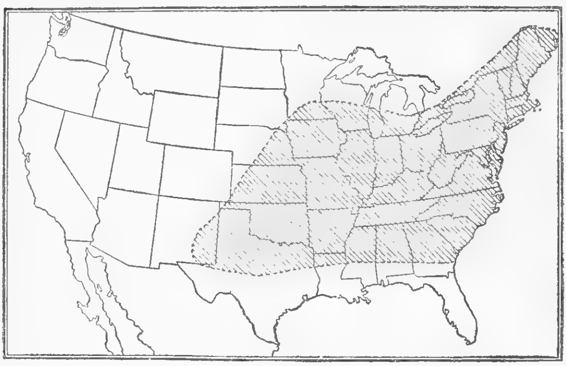


FIG. 1.—Distribution of the roundheaded apple-tree borer (*Saperda candida*).

DISTRIBUTION.

The known range of the roundheaded apple-tree borer may be bounded by a line extending from near the mouth of the St. Law-

[1] Numbers in parenthesis refer to "Literature cited," p. 41.

rence River westward through Quebec and Ontario to Minnesota, thence in a southwesterly direction through Nebraska, Kansas, and New Mexico to Texas, and thence eastward through Texas, Louisiana, Mississippi, Alabama, and Georgia to the Atlantic coast. (See fig. 1.) There seem to be no data showing that the general range of the species has been greatly extended by the development of the orchard industry of the country.

Within the bounds of its range there are many limited districts where the borer does not occur, or, at least, where it is very uncommon. Just why this is true can not be fully explained, but the absence of native host trees and the abundance of those species of woodpecker which prey upon the borers are two factors which often have much to do with the local scarcity of the pest. Areas of comparative freedom and corresponding areas that are heavily infested often exist near together for years at a time with little relative change. This occurs in native woods as well as in orchards. The peculiarity may be partly explained by the tendency of the species to colonize or form family breeding centers, far from which the adult females do not habitually wander.

FOOD PLANTS.

Probably no other tree is so subject to attack by this borer as the quince. Wherever the borer is common it is difficult to succeed with this fruit. Quince trees are usually small and one or two borers can injure greatly or kill a tree in a single year. The habit which the quince has of sending up suckers or sprouts around the central stem tends to give the borers a good chance to work. In the bases of such clumps borers are hard to reach in the worming process and there they may find positions where woodpeckers can not get at them. Apple is undoubtedly the second choice, and probably mountain ash (*Sorbus americana*) is next in favor. Of the cultivated fruits, quince, apple, and pear are preferred in the order named. Mountain ash, service (*Amelanchier canadensis*), wild crab (*Pyrus* spp.), hawthorn (*Crataegus* spp.), and chokeberry (*Aronia* spp.) are native hosts which are attacked about in the order stated. There are records in the Bureau of Entomology of the development of this borer in peach, but it is certain that this tree is very rarely attacked.

In one instance in West Virginia all the host trees of this borer which grew on a certain tract of woodland and grown-up field were cut and examined to determine the relative extent of infestation of each species of tree. The trees examined numbered 1,483 and the results of the count are given in Table I. It is probable that in any adjacent locality a considerable variation from these figures might have been found, yet the results of the count showed what is apparently a constant preference for apple over the other species of host trees present in this instance.

TABLE I.—*Relative numbers of roundheaded apple-tree borers found in different species of host trees at French Creek, W. Va.*

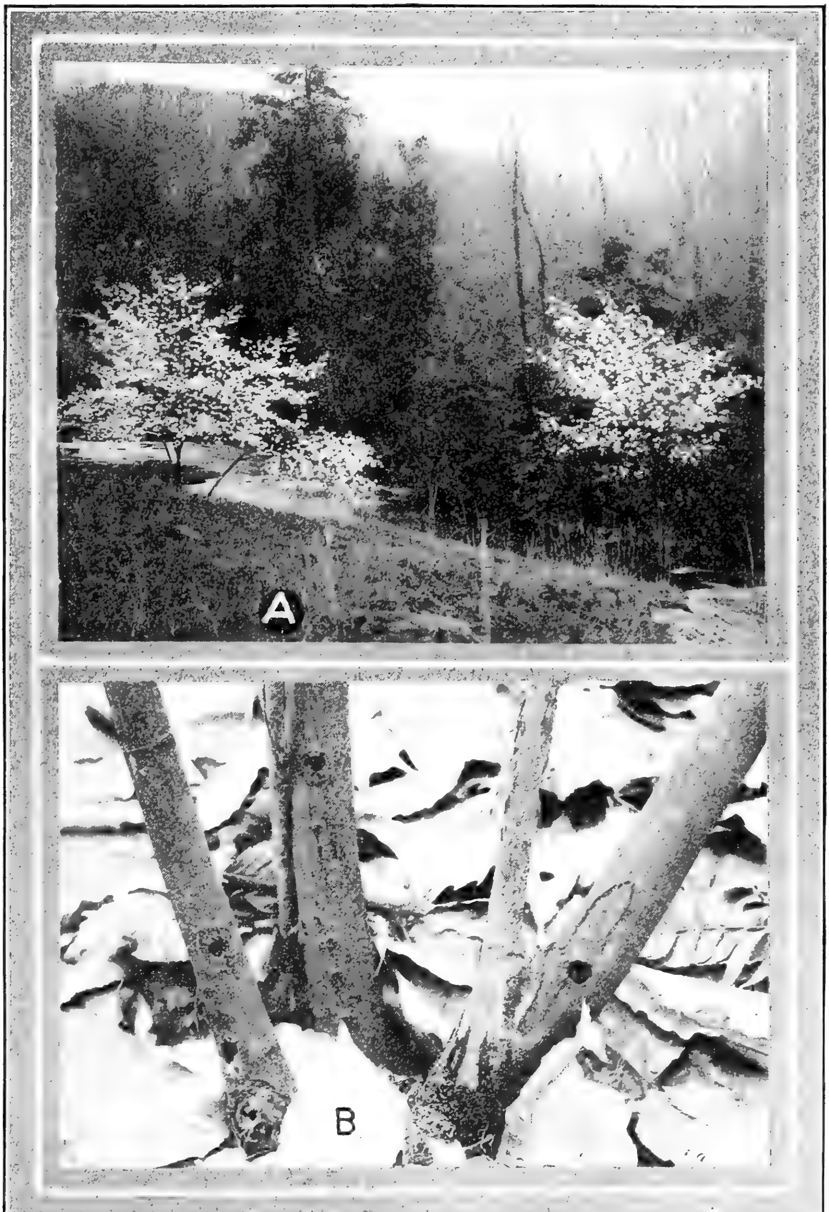
Trees examined.		Number of borers.
Number.	Variety.	
194	Seedling apple	85
11	Pear	0
823	Wild crab	9
405	Hawthorn (Crataegus)	1
50	Service	0
1,483	Total	95

It will be noted from Table I that in this case the 50 service trees (Pl. I) examined contained no borers. This is far from the rule as regards the service, for in woods where that tree and mountain ash abound tracts are often found where practically every tree is infested. (Pl. I, B.) Other areas near by of equal size are quite likely to occur where no borers can be found, although the host trees may be just as abundant as where infestation is general. This arises from the fact that under natural conditions families or communities become established and reproduce through many generations within restricted areas. It is probable that adult males fly readily from one breeding center to another, preventing thereby an excess of interbreeding, but the females do not normally tend to go far from the tree in which they developed, provided other host trees are near. This tendency for infestation to be confined to limited groups of trees is often noted in cultivated orchards. Isolated trees are sometimes attacked, however, and there is no question that the female is capable of flying to a considerable distance when impelled by a scarcity of trees in which to oviposit.

DISTRIBUTION AS AFFECTED BY NATIVE HOST PLANTS.

As has been pointed out, the principal native host trees of the roundheaded apple-tree borer are the service, mountain ash, wild crab apple, and hawthorn. Of these wild hosts service and mountain ash seem to be preferred to the others. It is an interesting fact that the service tree (Pl. I, A) occurs over practically the same region of North America as does the insect in question.

These wild food plants undoubtedly play an important part in the local and general distribution of the borer. Infestations commonly attributed by orchardists to certain soil conditions, to newly cleared land, or to the hilly contour of the land are in reality usually due to



ROUNDHEADED APPLE-TREE BORER.

A, Blooming service trees, *Amelanchier canadensis*. At this season of the year borers are undergoing transformation to beetles. B, Exit holes of beetles in clump of young service trees.

ROUNDHEADED APPLE-TREE BORER.

Wire-screen cages used on infested apple trees to hold escaping beetles.

the proximity of the insect's breeding places, the breeding places quite often consisting of these wild host trees that thrive on account of favorable soil, elevation, or other local conditions. Orchards established on newly cleared lands and in hilly locations are more likely to have woods or neglected thickets of wild crab apple, seedling apple, or hawthorn growing near to them than are orchards in the more valuable and highly cultivated valley or level lands. The wild host trees that grow in the woods and thickets (Pl. I) are usually breeding places for the borer, and the adult insects that develop within them fly to the orchards near by and deposit their eggs. In some localities of the Shenandoah apple region the idea is prevalent that borers discriminate between soils and prefer the shale lands of the hills rather than the clay and loam of the valleys. The greater abundance of borers in hill orchards, however, can be explained by the prevalance in such localities of the wild trees in which they breed (Pl. VII, C), the soil having only the indirect bearing on the situation that the shale lands favor the growth of service and other wild host trees.

The native service tree (Pl. I) is perhaps the most effective distributor of this insect. In about 25 localities within the States of Maine, Michigan, Pennsylvania, West Virginia, Virginia, North Carolina, Georgia, Alabama, Mississippi, and Florida, where careful investigations were made, the absence, scarcity, or abundance of service trees was accompanied by a corresponding absence, scarcity, or abundance of the roundheaded apple-tree borer.

CHARACTER OF INJURY.

About 95 per cent of the eggs (Pl. IV, B, C, E) of this borer are deposited within the bark at the base of the tree trunk. (Pl. III.) Usually the eggs are within 6 inches of the ground, but occasionally they are placed in a crotch of the tree or even in a branch 10 or 15 feet above ground. The larva (Pl. V, A, B; VIII, A), which hatches in early summer, feeds at first on the inner bark, eating out a roughly circular space about the oviposition scar and ejecting stringy, sawdustlike castings of a reddish color through small openings in the outer bark. (Pl. V, C.) As the larva develops it extends its gallery either up or down the tree or transversely with the grain of the bark and before the end of the first season may burrow into the wood. (Pl. V, A, B.) More frequently, however, it spends the first winter in the inner bark and enters the wood the second summer. The burrows, both in the bark and wood, are broad and irregular in form, and, with the exception of a space about the borer (Pl. VI, D), are packed with digested wood particles (Pl. VII, A, C). The borer feeds from about the blooming time of apple in the spring until late in the autumn and continues to throw out castings until it begins the construction of its pupal quarters. (Pl. VII, A.)

Trees of all ages are attacked, but the most severe injury is done to young trees, in which the wound made is greater in proportion to the size of the trunk. (Pl. IV, D.) Frequently a number of borers will attack a single tree and girdle it completely or so riddle and weaken the heartwood that the tree will break over at the surface of the ground. It is not unusual to find a dozen borers in one tree, and on one occasion the writer found 25 within an 8-year-old apple tree. Felt and Joutel (6) cite an instance where 30 borers were removed from one tree.

Trees severely injured by borers present a sickly appearance, the foliage being sparse and of a pale green color. (Pl. VI, A.) When of bearing age they are inclined to bloom freely and set heavy crops of fruit, the fruit developing poorly and the trees often dying in an effort to bring the crop to maturity. If any part of an orchard is bounded by woods the first and most severe injury usually occurs among trees near to such woods.

METHODS USED IN SECURING BREEDING MATERIAL AND REARING THE INSECTS.

In the rearing work connected with this investigation many individual insects were carried through from eggs to adults in young apple trees planted for the purpose. Larger apple trees were used in which to plant newly hatched borers for rearing purposes. The trunks of some trees were made to support and bring to maturity as many as 25 borers. Each spring a large number of pupæ were secured by scouring the roadsides, grown-up fields, and neglected orchards of various localities for small, worthless seedling-apple trees in which the insects were maturing. Such trees were cut near the ground and short sections of the base of the trunk containing the pupæ sawn off and taken to the insectary, where they were kept in rearing cages. Many pupæ were also chiseled out of trees and placed in small glass vials excluded from the light. About 75 per cent of the pupæ kept in the vials developed into normal adults.

CAGES USED FOR REARING AND OBSERVING BORERS.

In carrying on the work herein described three types of fine-meshed, wire-screen cages were used. The first were small cylinders fitted around the bases of trees in which borers were developing (Pl. II). These cages were about 15 inches in length, the lower end when in place being sunk in the earth for half an inch and the space at the top between the wire and tree packed with cotton batting. Such cages excluded woodpeckers, imprisoned emerging beetles, and were useful in other ways in preventing the disturbance of the insects. A larger form of cage was made by stretching wire over a light wooden frame 2 by 2 by 4 feet in dimensions. Cages of this type were used to set over apple trees 3, 4, or 5 years of age that had been headed low and pruned in for the purpose. When in place these cages were mounded slightly with earth at the bottom to prevent the escape of the beetles and were secured from wind by being attached with screws to posts driven into the ground at the corners. In these cages many beetles were confined over growing trees. and, so far as could be observed, lived lives comparable in length with those in the field. Several other cages of larger size were built over clumps or short rows of young apple trees. Some of these cages were 20 feet in length by 8 feet wide and 8 feet high. They were provided with tight-fitting doors large enough to admit a man and were used for observations on the various stages of the borer and for testing control measures.

THE EGG AND OVIPOSITION.

THE EGG.

The egg (Pl. IV, B, C, E) when first deposited is yellowish white, assuming a darker shade within a few days. It is 3.5 to 4 mm. in length by 1 to 1.5 mm. in width, slightly flattened, both ends tapering to rounded points, the shell tough and plastic, bending somewhat in conformity to the space which it occupies. There is considerable variation in size and shape.

THE OVIPOSITION PROCESS.

Egg laying usually begins a week or ten days after the female beetles leave the wood. In preparing to oviposit, the female assumes an oblique position on the bark (Pl. III, A) and with her jaws makes a slightly curved slit in the bark 4 or 5 mm. in length, and usually extending parallel with the grain of the bark. (Pl. IV, A.) After the incision is completed, the beetle turns, inserts the tip of the ovipositor into the opening, and with considerable effort forces it into the tissue, usually between the bark and wood. (Pl. IV, B, C.) The ovipositor is inserted at about the center of the slit made with the mandibles and is extended under the bark in a direction at right angles to the slit. The egg is placed with the end toward the slit and from 1 to 2 mm. from it at the nearest point. After the ovipositor is withdrawn a small mass of clear, gelatinous liquid is ejected into the hole, which dries and seals the egg chamber. Two or three minutes are spent in making the initial slit and twice that time in inserting the ovipositor, laying the egg, and sealing the opening. Several eggs are usually deposited at a time within one tree (Pl. IV), quite often the second slit in the bark being made joining and in line with the first. When the bark over eggs is peeled off the eggs adhere to the bark rather than to the wood. (Pl. IV, B, C.)

After the batch of eggs is deposited the beetle may crawl up the trunk to the branches or may move away on the ground for a little distance and then take wing.

TIME OF DAY DURING WHICH EGGS ARE LAID.

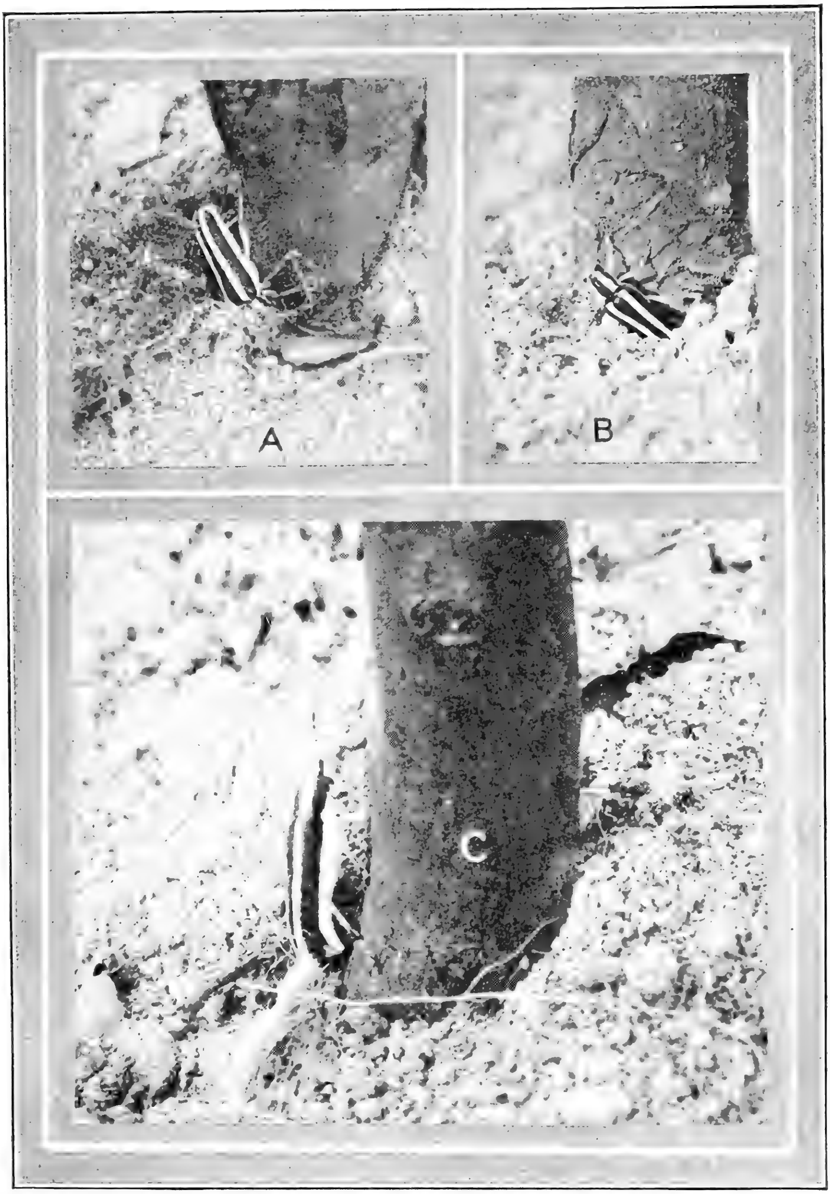
Most of the eggs are deposited during the hotter part of warm, sunny days. No evidence was obtained that oviposition ever takes place at night. In one case a female was found ovipositing at 5.30 a. m. and others were several times observed laying eggs near twilight in the evening, a time of special activity with both sexes of beetles.

PLACE OF OVIPOSITION.

As has been stated on another page, probably 95 per cent of the eggs of the roundheaded apple-tree borer are deposited in the trunks of trees within 6 inches of the ground; usually they are not more than 1 or 2 inches above the soil and quite often they are on a level with (Pl. III, C) or slightly below the surface. (Pl. III, A, B.) In rare instances eggs are deposited in the crotches of trees, around the edges of cavities in the trunk or larger branches, and even in small branches high up in the trees. In one case the writer found two larvæ working in a branch 15 feet above the ground. Usually woodpeckers remove the borers that begin operations aloft in the trees. Possibly the beetle's habit of ovipositing close to the ground has evolved from the greater dangers attendant upon the higher locations.

When the female beetle is ready to oviposit she usually crawls from among the branches downward along the trunk. In descending, if an obstacle of any kind is encountered she may pause and oviposit in the bark above it. This habit accounts for borers occasionally found in the crotches of trees. The writer found numerous eggs and larvæ above burlap bands which had been placed around the trunks of apple trees for trapping codling moth larvæ. When similar bands were placed on trees in cages the beetles laid more eggs above the bands than at the ground. In one test of this kind, comprising 5 trees and 5 female beetles, 36 eggs were laid above the bands and only 15 at the ground below the bands. These bands were attached around the trunks about 15 inches up from the ground.

The statement has been made that the females prefer to oviposit in the trunks of trees that are surrounded and shaded by weeds,



ROUNDHEADED APPLE-TREE BORER.

A, Female beetle splitting the bark of a young apple tree just below the surface of the ground preparatory to depositing an egg. Natural size. B, Female beetle placing an egg in the tree just below the surface of the ground. Natural size. C, Female beetle ovipositing at the surface of the ground. Slightly enlarged.

ROUNDHEADED APPLE-TREE BORER.

A, Oviposition scars in bark of young apple tree. Natural size. B, Inner surface of bark peeled from young apple tree, showing position of eggs. Natural size. C, Eggs in natural position. Much enlarged. D, Young borers attacking lower trunk of young apple tree. E, Eggs. Much enlarged.

litter, or water sprouts, and that trees so surrounded are more likely to be injured by borers than those having trunks exposed to the full light. Observations made by the writer, however, indicate that the beetles prefer to oviposit in the sunlight rather than in the shade. In one case 609 borers were removed from an orchard of 6-year-old apple trees which was located on a hillside having a general slope to the southwest. The trunks of the trees were long and one side received the unobstructed sunlight during a greater part of the day. The oviposition scars in which the borers hatched were found and those situated on the sunny side and shady side of the trunks were counted separately. As nearly as possible, each side was made to include half the circumference of the trunk. Of the 609 oviposition scars which were located, 393 were on the sunny or exposed side and 216 on the shaded side. The fact that about 65 per cent of the eggs had been laid on the more exposed side of the trees indicates that mulches of straw or hay placed around trees or the shading of the trunks by low branches does not attract the beetles, but rather repels them.

OVIPOSITION IN CAGES.

Other workers with this insect seem to have had but little trouble in inducing caged female beetles to oviposit in apple twigs, in sections of apple branches set in the ground, and even in apple fruits. The writer, however, has never been able to get a normal frequency of oviposition in any but growing trees. At one time 15 pairs of beetles were confined separately in roomy cages for a period of 17 days. Fresh apple branches, about an inch in diameter, were set in the ground daily in each cage. Although this was kept up from May 31 to June 17, a time when egg laying in the field was at its height, only 17 eggs were secured in the branches and 10 of the 15 females failed altogether to oviposit. The cages with the beetles were then removed and placed over small growing apple trees, whereupon oviposition began freely and at once. Attempts to induce caged females to oviposit in other than growing trees were made frequently, but never with entire success.

OVIPOSITION PERIOD.

As an example of the period of time over which eggs are deposited in a given locality, observations made in 1914 may be cited. During that year the first female issued on May 23. Eight days later she paired with a male and on June 4 laid her first eggs. No record was obtained of the last egg of this individual but other females continued to oviposit until August 1, the entire egg-laying period for the year covering 58 days. It is not unusual to find unhatched eggs in the field in the latitude of West Virginia from August 10 to 15, although none have been found after August 15. From these and from considerable other data obtained, it appears that normally egg laying continues in a given locality from 50 to 60 days, although perhaps no single individual oviposits over so long a period of time.

INDIVIDUAL EGG CAPACITY.

The number of eggs normally deposited by a single female beetle is not great, the average number having been found by different investigators to vary considerably. Felt and Joutel (6) mention 10 as being about the quota for one individual, while Becker (14), making observations in the Ozark Mountain regions, found the number to range from 16 to 93, with an average of 40.8 per female for five individuals. The writer obtained egg counts from 15 individuals, the figures being shown in Table II.

TABLE II.—*Individual egg capacity of female beetles of the roundheaded apple-tree borer at French Creek, W. Va.*

Year.	Number of females.	Number of eggs.	Average number of eggs per female.
1911	3	52	17.3
1914	1	17	17
1914	1	20	20
1914	1	22	22
1912	1	13	13
1912	1	20	20
1914	7	193	27.6
Total	15	337	....

Average number of eggs per beetle 22.5

Table II shows that the minimum and maximum numbers of eggs obtained from 15 beetles were 13 and 27.6, the average being 22.5. Since these records were obtained in several different years under conditions that were approximately normal they probably represent fairly accurately the average number of eggs laid by females in the locality mentioned.

PERIOD OF INCUBATION OF EGGS.

The time required for the eggs to hatch has been variously stated at from 8 days to 3 weeks. The writer noted the period in 8 instances, the data for which are set forth in Table III.

TABLE III.—*Period of incubation of the roundheaded apple-tree borer at French Creek, W. Va.*

Dates on which eggs were laid.	Dates on which eggs hatched.	Number of eggs.	Number of days required to hatch.
June 14	June 28	1	14
June 12	do	1	16
June 9	June 25	1	16
Do	June 26	1	17
June 10	June 23	1	13
June 13	June 29	1	16
Do	June 30	1	17
Do	July 2	1	19

Average period of incubation .... 16 days.

As is shown in Table III, the minimum and maximum periods of incubation were 13 and 19 days, the average for the 8 eggs being 16 days. Evidence was obtained that hatching is retarded by low and accelerated by high temperatures.

THE LARVA.

The larva (Pl. V, A, B) is a cream-colored, footless grub, with brown head, blackish mandibles and a conspicuous patch of small, brown tubercles on the posterior half of the broad, flattened dorsal surface of the first thoracic segment. The intersegmental constrictions are deep and the dorsal and ventral surfaces of the first seven abdominal segments are elevated and roughened. The sides of the body are sparsely covered with short, stiff hairs. When full grown, the length is from 30 to 40 mm., the females being considerably larger than the males. According to Becker (14) there may be as many as six larval instars.

DEVELOPMENT AND FEEDING HABITS OF THE LARVA.

The behavior of the larva varies as affected by individual characteristics, difference in size, vigor, and species of host trees, and difference in localities, so that no one description of the larval development will apply to all. In the latitude of West Virginia the activities and growth of the larva when feeding under normal conditions in apple are about as follows: The larva begins to feed at once after leaving the egg and soon eats out a broad, irregular, usually more or less circular burrow around the point where the egg was laid. At this stage of its life growth is rapid and the borer soon forms a broad, elongate gallery under the bark which may extend in any direction away from the point first attacked. As winter approaches there is some tendency to burrow downward to or beneath the soil, but this is by no means general.

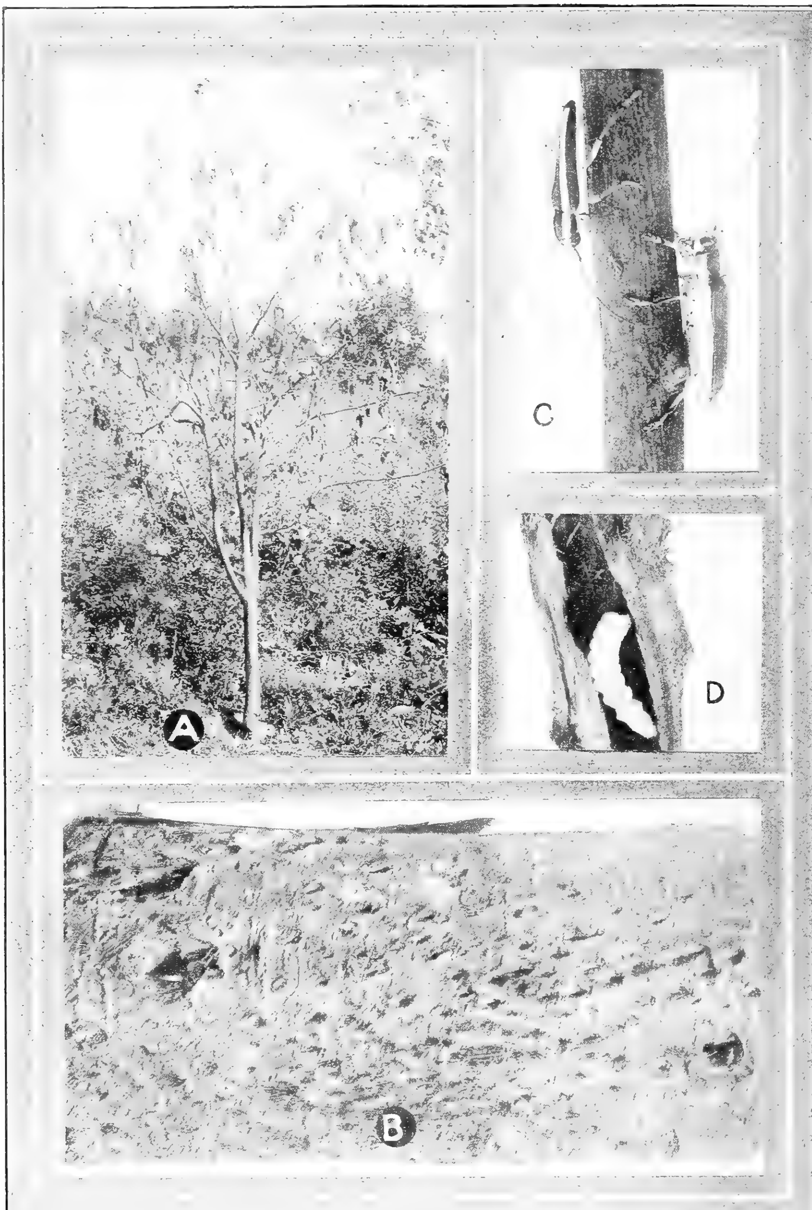
At first the feeding is all in the bark and the point of injury usually shows from the outside as a dark, slightly depressed spot from which castings are ejected and from which a small quantity of sap often flows. In some cases the borer burrows into the wood the first season, but usually it does not enter the wood until the succeeding spring. In small trees the galleries penetrate to the heart, but in old trees they are seldom extended more than an inch beneath the inner bark. The burrows in the wood, like those in the bark, are broad and irregular in shape and usually extend both above and below the surface of the ground. In the northern part of the insect's range a greater proportion of the feeding seems to take place beneath the ground. The writer found larvæ in Maine burrowing downward in the roots to a distance of a foot or more from the base of the trunk, a depth which does not seem to be reached in the South. Many 1-year-old larvæ were also found in Maine that had not yet penetrated into the wood but were still feeding in the bark near the old oviposition scars. In all their feeding larvæ keep an open space about themselves, to allow of free movement, but pack the balance of their burrows with wood fragments. Strings of reddish-brown castings are also thrown out from the tree through small openings in the bark. (Pl. V, C.)

In the late summer and autumn preceding the spring during which pupation is to take place, the larvæ excavate galleries leading up the trunk of the tree a short distance beneath the bark. (Pl. VIII, A, B.) At the upper end of this gallery the pupal chamber is formed by slightly enlarging the circumference of the opening and curving the upper end outward to the inner bark. (Pl. VII, A.) The curved upper end is packed lightly with wood dust and a considerable space in the gallery below the pupal chamber is filled with short, excelsior-like strings of wood torn from the walls of the opening. (Pl. VIII, A.) The space for the pupa is often 2 inches or more in length and both the larvæ and pupæ when occupying it recede or advance when disturbed, evidently a provision for escaping woodpeckers. The pupal quarters usually are practically completed in the autumn but the larvæ add finishing touches in the spring before they pupate. In small trees the exit holes at the upper end of the pupal chambers are usually within from 4 to 8 inches of the ground, but in large trees it is not unusual to find the place of exit at the terminus of a gallery extending upward from the ground to a distance of 18 inches or 2 feet. Just why the pupal quarters should be made higher in large trees than in small trees does not seem to have been determined.

Wintering larvæ begin activities early in the spring and continue to feed until stopped by the cold weather of winter. Probably the annual feeding period in the South is much longer than in the North.

ROUNDHEADED APPLE-TREE BORER.

A, Borer, first summer in tree. Natural size. B, Second summer in tree. Natural size. C, Castings being ejected from tree by borer.



ROUNDHEADED APPLE-TREE BORER.

A, Young apple tree dying from injuries caused by roundheaded apple-tree borers. B, Trunk of young apple tree marked by beak of woodpeckers searching for borers; the larger wounds show where borers have been removed. C, Adult roundheaded apple-tree borers; male above and female below. Slightly enlarged. D, Borer in apple tree; showing cleared space maintained in burrow to allow of free movement of body. Natural size.

ROUNDHEADED APPLE-TREE BORER.

A, Pupæ in natural position in tree. B, Castings of borers at base of young apple tree. C, Borers in young service tree. D, Exit holes of beetles.

ROUNDHEADED APPLE-TREE BORER.

A, Larvæ within pupal chambers in young apple tree. Natural size. B, Cross section of base of trunk of young apple tree, showing galleries made by borers in ascending the trunk to pupate. Natural size. C, Beetle resting by exit hole. Natural size.

FORM OF BURROWS IN PEAR DIFFERS FROM THAT IN APPLE.

It was frequently noted that the borers in pear trees formed differently shaped burrows from those made in apple. In pear the burrow is much more elongate, often being a slender gallery 6 or 8 inches in length and extending around the trunk, sometimes almost or entirely encircling trees several inches in diameter. As the larvæ in pear near maturity they enter the wood and pupate much as in apple.

PERIOD SPENT BY LARVA IN THE TREE.

Ever since the roundheaded apple-tree borer began to attract the attention of entomologists there has been some disagreement as to the number of years spent by the larva in the tree. Practically all writers have agreed that the life cycle requires either two or three years for completion. Most of the well-known textbooks on general entomology, as well as the systematic treatise on this particular species, give three years as the life period. Comstock (4, p. 573) says "It requires nearly three years for this larva to attain its growth." Smith (5, p. 209–210), speaking of the larva, says "In the spring of the third year [it] changes to a beetle." Felt and Joutel (6) give a three-year period in the tree. Saunders (8) says "It is generally conceded that the larva is three years in reaching maturity." Sanderson (12) says "The third spring the larvæ transform to pupæ." Slingerland and Crosby (13) state, "It is generally believed that it requires three years for this apple-borer to complete its life cycle." Lutz (15, p. 359) says, "From egg to adult takes three years." Chittenden (7) gives a three-year life cycle. O'Kane (11) says "The larva requires three years for maturity." Both Smith (10, p. 52–54) and Patch (9) give a three-year larval period. Becker (14) says "*Saperda candida* has a two-year life cycle in the Ozarks," but points out that "There seems to be some indication that occasionally a larva may require three years for its development."

The present investigation has shown that the length of the life cycle averages longer in the North than in the South and also that this period may vary several years in length in a given locality. Table IV shows the years required for 121 insects to reach maturity at French Creek, W. Va.

TABLE IV.—*Period of life cycle of the roundheaded apple-tree borer at French Creek, W. Va.*

Year beetles issued.	Number years in tree.				
	1	2	3	4	5
1913	0	9	0	0	0
1914	0	11	2	0	0
1915	2	7	1	0	0
1916	0	36	10	1	0
1917	0	40	2	0	0
Total	2	103	15	1	0
Per cent	1.7	85.1	12.4	0.8	......

Table IV shows that out of 121 individuals, 2 issued from the wood as beetles the next year after the eggs were deposited, 103 issued in two years, 15 in three years, and 1 in four years.

Records of the exact number of days elapsing from the deposition of the eggs to the issuing of the beetles were ascertained in a number of instances. These records are shown in Table V.

TABLE V.—*Number of days between deposition of egg and emergence of beetle of roundheaded apple-tree borer at French Creek, W. Va.*

Date egg was deposited.	Date beetles issued from wood.	Number of beetles.		Number of days from egg to beetle.
		Male.	Female.	
June 18, 1913	June 1, 1915	1	0	713
Do	June 14, 1915	0	1	726
Do	June 8, 1915	0	1	720
June 15, 1914	May 24, 1916	2	0	708
June 18, 1914	do	2	0	705
June 8, 1914	May 25, 1916	1	0	716
June 12, 1914	do	1	0	712
June 18, 1914	May 26, 1916	1	0	707
June 18, 1913	May 27, 1916	1	0	1,073
June 18, 1914	do	0	1	708
June 16, 1914	May 28, 1916	0	2	711
June 18, 1914	do	0	1	709
June 11, 1914	do	0	1	716
June 18, 1913	do	0	1	1,074
June 11, 1914	do	1	0	716
June 16, 1914	May 29, 1916	0	2	712
Total		10	10	

As is shown in Table V, 1 male spent 1,073 days in undergoing development within the tree and 1 female 1,074 days, a 3-year period for each. All the others reached maturity in 2 years, the 9 males requiring on an average 710 days from egg to adult and the 9 females undergoing the same transformation in an average of 714 days.

Records obtained at Winthrop, Me., show that of 24 individuals, none matured in 2 years, 6 issued as beetles in 3 years from the egg, and 18 required 4 years to develop from eggs to adults. No definite records were obtained for individuals requiring longer than 4 years for development and yet observations were made which indicate a 5-year period in some cases. Observations made at Biltmore, N. C., indicate a 2-year period with most individuals in that locality.

THE PUPA.

The pupa (Pl. VII, A), when first formed, is soft and delicate, the color being similar to that of the larva. Within a few days it turns slightly yellowish, the eyes soon take on a dark color, and later the whole body becomes mottled with brown and blackish markings. The pupa occupies a vertical position in the cell and measures from 18 to 25 mm. in length, the females being much longer and more robust than the males.

PERIOD OF PUPATION.

At French Creek, W. Va., practically all the individuals pass through the pupal stage during the period from April 15 to May 15, although the time of pupation and the duration of the stage depend very much on weather conditions. The earliest pupa was found in the field April 12, 1913, and the latest May 20, 1915, although undoubtedly a few may sometimes occur before and after these dates. In the locality mentioned, the entire pupal period for any one year has not been found to extend over 30 days, the pupal stage for a single individual averaging about 20 days. All transforming individuals were found in the pupa stage at Demorest, Ga., on May 1, 1915; at Winthrop, Me., on June 17, 1916; and at Munising, Mich., on June 20, 1917.

As has been stated, the pupæ are sensitive to temperatures, warm weather accelerating and cold weather retarding the changes. After transforming to the adult stage the beetles usually remain within the pupal chamber from 5 to 10 days, the length of this period, too, depending on weather conditions.

THE ADULT.

The adult (Pl. VI, C; VIII, C) is a handsome, elongate beetle, the males averaging 15 mm. in length and the females 20 mm. The back is cinnamon brown with two broad white stripes extending the full length of the body; the front of the head and underparts are silvery white and the legs and antennæ gray, changing to brownish at the extremities. The antennæ of the males are slightly longer than the body and those of the females slightly shorter than the body.

In escaping from the wood the beetles gnaw round exit holes through the bark at the upper end of the pupal chamber, the holes ranging from 5 to 8 mm. in diameter, the larger ones being those from which females issue (Pl. VII, D).

PERIOD OF ACTIVITY OF BEETLES.

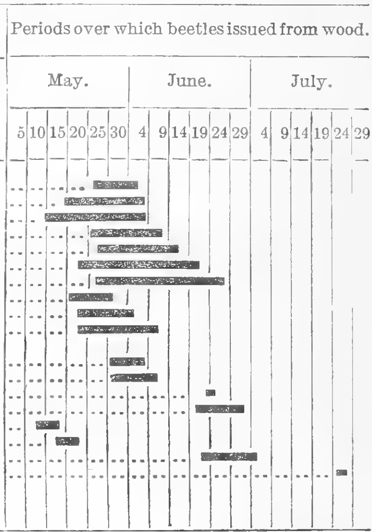
The statements of other investigators regarding the length of time that the beetles of the roundheaded apple-tree borer are on the wing indicate that in some places this period may be of longer duration than in any of the localities where the present writer has made observations. Becker (14), in the summary of his paper, says that in the Ozarks pupation begins in the latter part of March and may continue until the middle of June, and on another page speaks of larvæ that pupated as late as July 11, the inference being that this was under normal conditions. The beetles are said by the same author to be on the wing in the Ozarks from the third week of April until perhaps as late as the last of August. These statements indicate that in the Ozarks beetles continue to issue from the wood over a period of approximately 100 days. Chittenden (7) states that oviposition has been observed from June to September in a single locality (Lawrence, Kans.) and says that at Albany, N. Y., beetles have been observed in the trees as early as April. Felt and Joutel (6) cite statements of observers giving the months of May, June, July, and August as the time when beetles are abroad.

All the rearings of the present writer indicate that the beetles issue from the wood over a much shorter period than has been found by the writers referred to above. The longest periods covered by the emergence of the beetles were at French Creek, W. Va., where, in 1916, 244 beetles issued from May 20 to June 18, a period of 30 days, and in 1917, when 118 beetles issued from May 25 to June 23, a period of 30 days. No beetles in either year issued before the first dates or after the last dates named. In all the rearings of which the dates of issue were kept, including 772 beetles, the first to issue was at Demorest, Ga., on May 8, and the last at Munising, Mich., on July 23, the interval between these two extreme dates being 78 days.

Table VI presents the data which have been accumulated relative to the time of emergence of beetles in several localities.

TABLE VI.—*Periods during which beetles of the roundheaded apple-tree borer issued from the wood in different localities.*

Year.	Locality.	Number of beetles.	First and last emergence.	Number of days.
1911	French Creek, W. Va.	11	May 23–June 1	10
1912	do	27	May 14–June 6	24
1913	do	95	May 12–June 6	26
1914	do	116	May 22–June 8	18
1915	do	5	May 25–June 14	21
1916	do	244	May 20–June 18	30
1917	do	118	May 25–June 23	30
1918	do	21	May 18–May 28	11
1914	Weston, W. Va.	35	May 20–June 2	14
1914	Great Cacapon, W. Va.	13	May 20–June 6	18
1914	Elkins, W. Va.	16	May 28–June 5	9
1914	Pickens, W. Va.	24	May 28–June 9	13
1914	Pemberton, N. J.	1	June 21	1
1914	Winthrop, Me.	28	June 18–June 30	13
1915	Demorest, Ga.	6	May 8–May 14	7
1915	Biltmore, N. C.	2	May 15–May 20	6
1916	Winthrop, Me.	8	June 20–July 3	14
1917	Munising, Mich.	2	July 23–July 25	3
	Total number beetles	772		



LENGTH OF LIFE OF INDIVIDUAL BEETLES.

Eight female beetles whose emergence and death were noted in 1911 and 1912 lived, respectively, 27, 31, 37, 41, 41, 44, 46, and 46 days. In 1912 the first beetles issued from the wood on May 14 and eggs were still being deposited on July 1, 48 days after the first beetles appeared. In 1913 beetles were observed on the wing from May 12 to July 19, a period of 68 days. In 1914 a female issued on May 27 and died July 24, living 58 days. In the same year a male and female were alive on August 6, 76 days after the first beetle issued. In 1917 the first beetle left the wood on May 25 and the last beetle of the year died August 10, beetles thus being on the wing for 77 days. In 1918 two females were observed to be alive and active 61 days after leaving the wood. The beetles referred to above were in all cases kept in roomy wire-screen cages over small, growing apple trees, and it is presumed that their life periods extended over the normal term.

FEEDING HABITS OF BEETLES.

The beetles feed to a considerable extent upon both tender and tough bark of twigs and branches and upon leaf stems and leaf ribs, and they frequently chew ragged holes through the tissues of the leaf. (Pl. IX, A, C.) They were observed often working with their mandibles at the castings ejected from trees by larvæ of their own kind and were seen occupied in a similar manner with damp soil; this was probably for the purpose of obtaining water. One female beetle kept alone in a cage over a young apple tree lived for 58 days, and after her death a careful measurement was made of the leaf and bark surface over which she had eaten. The total area eaten was found to be 6.9 square inches. In another instance two male and three female beetles, which had just issued from the pupal quarters, were placed in a roomy cage over a young apple tree that had been sprayed just before with lead arsenate at a strength of 3 pounds of the paste to 50 gallons of water. Two of the beetles died the first day, one died on the second day, one on the third, and the other, a female, died on the ninth day. All apparently succumbed to the poison, as there was no mortality among beetles caged at the same time over unsprayed trees. Death occurred to all the beetles confined over the sprayed tree before any eggs were deposited. It was noted frequently that beetles differed individually in the amount of feeding done immediately following their emergence from the wood, some proceeding to feed at once and others waiting several days. It is probable that the female referred to above, which lived nine days over the sprayed apple tree, did no feeding until a short time before her death.

COPULATION.

Copulation may take place soon after the beetles issue from the pupal chambers or it may be deferred a week or 10 days, the time of pairing seemingly depending about as much upon the volition of one sex as the other. Newly emerged males occupying cages in company with females have been observed to wait several days before paying any attention to the females. In other cases they have begun courtship on the day following that of their emergence. The females usually repel the males for several days, but will sometimes receive them within an hour after quitting the pupal quarters. Evidently some individuals of both sexes remain in the wood until they are sexually mature, while others issue before the sex instinct has developed.

The act of copulation usually lasts several hours and is repeated at frequent intervals so long as both sexes live and are active. Pairing was several times noted after the participants had been on the wing from 30 to 40 days.

Females confined by themselves were observed to engage in a performance evidently to attract males. They would occupy the upper surface of an exposed leaf and thrust out the ovipositor to its utmost length and then wave it about while it was being gradually drawn in. A few minutes later the ovipositor would be again extended and then drawn in and so the act would continue for an hour or more. Apparently a scent or influence of some kind was being discharged as a sex attraction, but when females so engaged occupied outdoor cages no wild males of the locality were observed to come to the cages.

DAY AND NIGHT ACTIVITIES OF THE BEETLES.

Early writers on this insect described the beetles as being active nocturnally and secreting themselves by day. The beetles were supposed to issue from their pupal cells and deposit their eggs exclusively by night. The reverse of this habit, however, has been found more nearly true. All the beetles issue from their exit holes by day, usually during the forenoon, although a few continue to come forth during the afternoon hours. No evidence was obtained that oviposition ever takes place in the darkness, although male beetles are occasionally on the wing at night. There is a period of activity in the evening just before twilight when both sexes are especially inclined to flight, but as darkness comes on most of the beetles settle among the branches and remain quiet until the light of the morning.

Observations made at night with electric flashlights indicated that the normal habit is to rest in one place through the night, but that occasionally the beetles move about in the darkness.

DO THE BORERS DIFFERENTIATE BETWEEN VARIETIES OF APPLE?

Orchardists often observe what appears to be a preference on the part of the roundheaded apple-tree borer for certain varieties of apple. Individual trees or blocks of one kind of apple will be attacked year after year much more extensively than those of other varieties. Becker (14) concludes from experiments that the borer does not discriminate between varieties and that the preference which is often indicated is merely a matter of propinquity.

During the present investigations observations were made bearing on this point over a period of five years in the experiment orchard at Elkins, W. Va., As has been stated, this orchard contained only three varieties, namely: 310 King, 341 Grimes, and 341 York Imperial, the block of Grimes occupying a space through the center of the orchard. All the rows of the three varieties abutted impartially at one end against an older and heavily infested orchard. There were no conditions within or surrounding the orchard that would appear more favorable for the attack of one variety than another, except that female beetles in entering the orchard to oviposit might be expected to alight more frequently on the outer trees. During four of the five years over which counts were made, however, the Grimes in the center were much more severely attacked, practically 50 per cent of the 1,639 borers removed from the trees being found in this block. The King trees, although fewer in number, were second in point of attack, and the York Imperial trees suffered least. This ratio of attack, as may be seen from Table VII, was constant for the years 1913, 1914, 1916, and 1917. In 1915, which was the year of lightest infestation, the York Imperials were first in point of attack, the Grimes second, and the Kings third.

TABLE VII.—*Relative extent of infestation by the roundheaded apple-tree borer of three varieties of apple for a period of five years.*

Year.	Variety of apple.					
	King.		Grimes.		York Imperial.	
	Number of borers.	Per cent.	Number of borers.	Per cent.	Number of borers.	Per cent.
1913	49	30.3	77	47.5	36	22.2
1914	80	33.5	110	46.0	49	20.5
1915	8	8.3	43	44.8	45	46.9
1916	223	35.4	283	44.8	125	19.8
1917	121	23.7	303	59.3	87	17.0
Total	481	29.3	816	49.8	342	20.9

It is entirely possible that the results which are shown in Table VII are accidental, and yet it must be confessed that, aside from varietal preference on the part of female beetles while ovipositing, there is no apparent way of accounting for the almost constant maximum attack of Grimes and minimum attack of York Imperial.

DISTANCE OF FLIGHT OF FEMALE BEETLES DURING OVIPOSITION.

The probability that the female beetle during her egg-laying activities does not normally wander far in search of host trees has been suggested by the fact that the trees containing the larvæ are usually found in somewhat restricted groups. This grouping of the borers occurs not only in orchards but in the woods as well, and indicates that where host trees grow near together the adult females during oviposition are not inclined to fly far from the trees in which they develop. In an effort to obtain data bearing on this point several experiments were carried out in West Virginia, which are described below.

THE DARNALL ORCHARD.

This orchard contained 537 apple trees ranging in age from 4 to about 20 years. In the summer of 1914 it was found to be badly infested with roundheaded apple-tree borers, and the trees were gone over carefully after the eggs of the current season had hatched, all the borers being removed and counted. The trees contained 141 borers, 106 of which had only recently hatched. The orchard was surrounded by pasture lands and woods in which grew an abundance of seedling apple, wild crab apple, hawthorn, and service trees. Within a strip 600 feet in width surrounding the orchard these outlying trees were also examined and all the borers removed and counted, the number of borers found being 95. This operation was repeated annually for a period of 4 years, it being obvious that if borers were not allowed to breed within the area all the young borers found within the orchard after the first year would necessarily have hatched from eggs deposited by female beetles which had flown into the orchard from outside the 600-foot strip.

In the second year of the experiment (1915) an examination of the orchard trees showed that female beetles had crossed the 600-foot strip and deposited 56 eggs. The third year (1916) only 1 egg was deposited in the orchard. The fourth year (1917) beetles flew across the boundary strip and deposited 44 eggs in the orchard trees. While this was a considerable reduction from the number of eggs deposited annually in the orchard before the experiment began, still it showed a rather general tendency on the part of the female beetles to fly at least 600 feet in searching for trees in which to oviposit.

In figure 2 are given plats of the Darnall orchard showing the location of infested trees and the number of borers found at each of the four annual examinations.

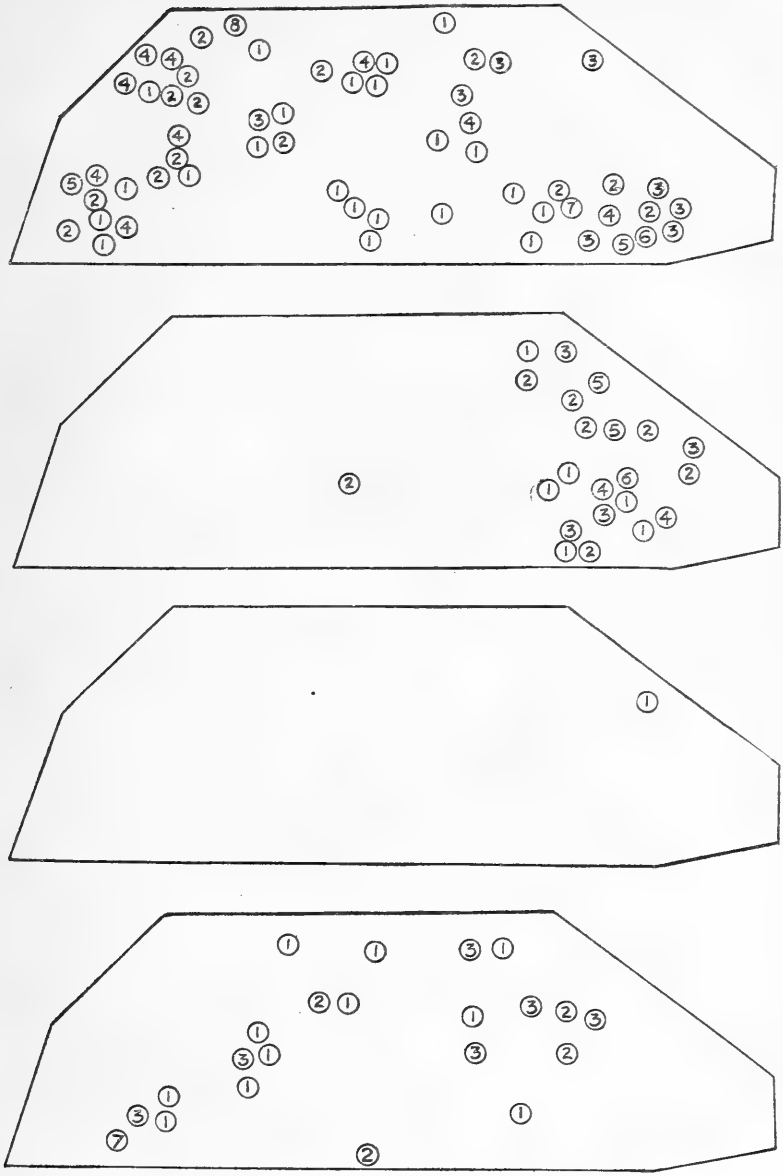


FIG. 2.—*Saperda candida.* Plats of Darnall orchard illustrating distance of flight of female beetles during oviposition. Circles represent location of infested trees and the figures within them show number of borers found. No beetles were allowed to develop within 600 feet of the orchard. Plat 1: Position of infested trees and number of borers found at first examination (1914). Trees contained 106 young borers and 35 from eggs of previous seasons. Plat 2: Position of 56 borers developing from eggs deposited in 1915 by beetles that had flown into the orchard from outside the 600-foot strip. Plat 3: Position of one egg deposited by female which entered the orchard from outside the 600-foot strip in 1916. Plat 4: Position of 44 eggs deposited by beetles which entered the orchard from outside the 600-foot strip in 1917.

THE PAGE ORCHARD.

The Page orchard, like the Darnall orchard, was found in 1914 to be heavily infested with roundheaded apple-tree borers. The trees within the orchard and within a strip 300 feet in width surrounding the orchard were cleaned of borers. The orchard contained 464 trees from which were removed 290 borers, 254 of which were from eggs of the current season. This orchard was surrounded entirely by pasture lands over which grew scattering seedling apple, crab apple, and hawthorn trees in which many borers were developing. The second annual examination, which was made in August, 1915, showed that 55 eggs had been laid in the orchard trees. One

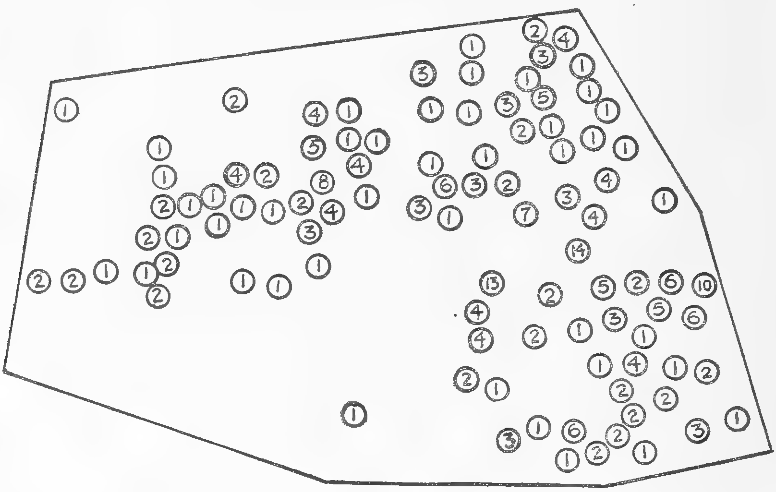


Fig. 3, *A*.—*Saperda candida*. Plat of Page orchard illustrating distance of flight of female beetles during oviposition. Circles represent locations of infested trees and the figures within show number of borers found. Orchard surrounded by 300-foot strip cleaned of borers. Plat 1: Infested trees and number of borers found at first examination (1914). Orchard contained 290 borers, 254 of which developed from eggs of the current year.

borer had been overlooked in the orchard during the examination of the previous year and this had developed into an adult female, as was apparent from the size of the exit hole, and near to the tree from which it issued two trees were found containing, respectively, 4 and 9 young borers. In another part of the orchard a group of 7 trees contained 42 young borers. This group of infested trees was near the outer border of the orchard, and 275 feet distant another fresh female exit hole was found in a seedling apple growing in the pasture field, the author of which had been overlooked the previous year. It seemed probable that this beetle had flown to the orchard and that the two females overlooked the previous year were responsible for all the eggs which were deposited within the orchard in 1915.

The third year (1916) 38 eggs were distributed among 10 of the orchard trees, all evidently having been laid by females that flew into the orchard over the 300-foot strip.

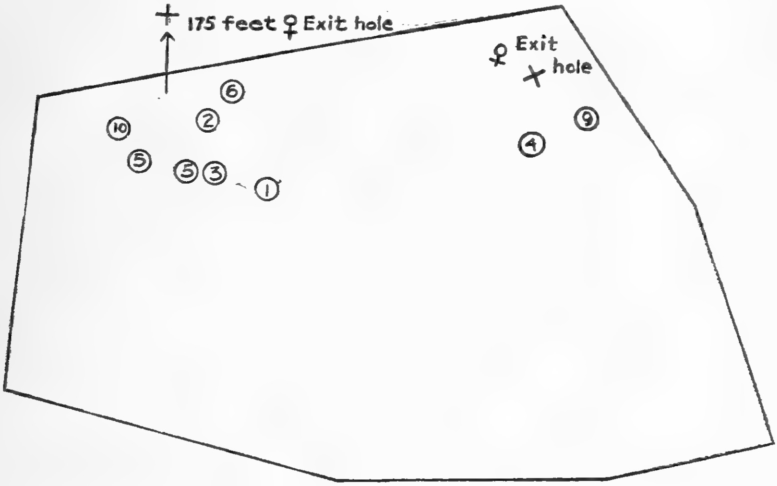


FIG. 3, *B.*—*Saperda candida.* Plat of Page orchard illustrating distance of flight of female beetles during oviposition. Circles represent locations of infested trees and the figures within show number of borers found. Orchard surrounded by 300-foot strip cleaned of borers. Plat 2: Number of borers found in second examination (1915). Fifty-five borers present from eggs of current season. Crosses indicate where two female beetles issued that had been overlooked as borers during the previous annual examination.

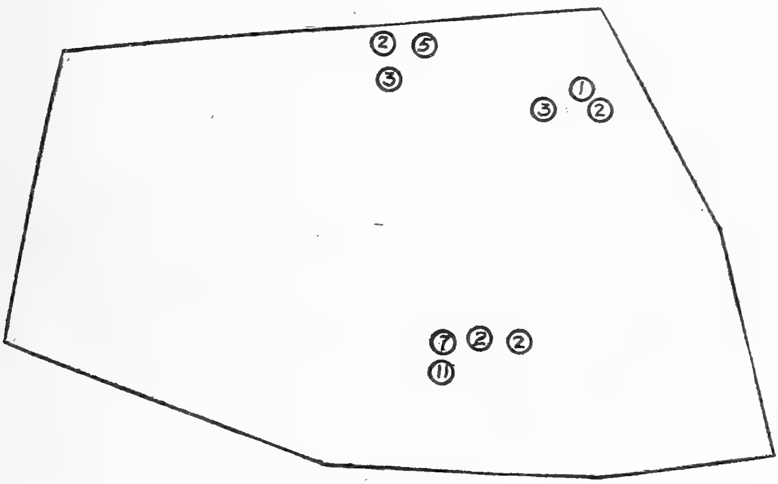


FIG. 3, *C.*—*Saperda candida.* Plat of Page orchard illustrating distance of flight of female beetles during oviposition. Circles represent locations of infested trees and the figures within show number of borers found. Orchard surrounded by 300-foot strip cleaned of borers. Plat 3: Number of borers found at third examination (1916). Thirty-eight borers were present, all having evidently hatched from eggs deposited by females which had entered the orchard across the 300-foot strip.

The Page orchard and the strip surrounding it were kept clean of borers for three consecutive years. The plats above (fig. 3) show the condition of the orchard as to infestation at each examination.

It will be seen that the results of the experiment in the Page orchard were fully as good as those obtained in the Darnall orchard, although the cleaned strip surrounding the trees was only half as wide. This may be accounted for by the fact that the breeding conditions for borers surrounding the Page orchard were much less favorable than those surrounding the Darnall orchard and fewer beetles were developing in the locality.

The results of the experiments described and illustrated above for determining the distance which beetles will fly during the period of oviposition are suggestive although not entirely conclusive. It will be noted that every year in both orchards after the experiments began there is evidence that female beetles crossed the surrounding strip of borer-cleaned territory to oviposit in the orchard. In all cases, however, there was a decided improvement in the borer conditions within the orchards after the development of beetles within cases, however, there was a decided improvement in the boror conditions of infestation on the number of young borers found in the orchards at the first examinations, we have thereafter percentages of borer reduction which may be tabulated as follows:

TABLE VIII.—*Improvement in roundheaded apple-tree borer conditions derived from preventing the development of adults within and adjacent to the orchards.*

Name of orchard.	Year.	Width of cleaned-up strip surrounding.	Number of borers found.	Percentage of gain.
		Feet.		
Darnall	1914	600	106	
Do	1915	600	56	47.1
Do	1916	600	1	99.1
Do	1917	600	44	58.5
Page	1914	300	254	
Do	1915	300	55	78.3
Do	1916	300	38	85.0
Total average gain in both orchards				73.6

As is shown in Table VIII, the average improvement in borer conditions in both orchards derived from the stopping of the development of adults in the immediate localities was 73.6 per cent.

FURTHER TEST OF THE FLIGHT OF FEMALE BEETLES.

One of the orchards used in experiments dealing with the roundheaded apple-tree borer contained 992 young apple trees planted in 31 rows of 32 trees each. Row 1 extended parallel with the outer row of an older orchard that was heavily infested with borers, the experiment orchard being surrounded on other sides by grown-up fields in which scattering seedling apple and service trees grew. Undoubtedly beetles developed within these outstanding trees and flew into the experiment orchard to oviposit, providing thereby for an unknown number of borers, which can not be eliminated from the numerical results of the experiment described below. The rather heavy infestation, shown below, of rows 1 to 5 can be accounted for only on the ground of an overflow of adult females from the adjacent older orchard.

In the experiment orchard during three separate years newly emerged beetles of both sexes were distributed among the trees of row 16, which extended through the center of the orchard. The beetles used were removed from rearing cages and placed on the trunks of the trees, care being exercised to disturb or excite them as little as possible. The sexes of the beetles were about equally divided as to numbers. After a sufficient time had elapsed for all the eggs to hatch which were deposited by the liberated females, the orchard was gone over and the number of borers found in each row recorded. The results showed with some degree of accuracy the extent to which the females in ovipositing wandered away from the trees upon which they were liberated. In 1914, 25 females were liberated on row 16; in 1916, 87 females were liberated on the same row; and in 1917, 12 were distributed in like manner. In the year 1915, nine females were liberated on row 29. In all cases males accompanied the females.

Table IX shows the distribution by rows of the borers found in the orchard each season following the liberation of the female beetles on row 16.

TABLE IX.—*Distribution of roundheaded apple-tree borers hatching principally from eggs deposited by female beetles liberated on the central row of the orchard. Orchard contained 31 rows of 32 trees each and beetles were placed on row 16.*

No. of row.	Number borers found.			Total.	No. of row.	Number borers found.			Total.
	1914	1916	1917			1914	1916	1917	
1	1	20	25	46	17	18	23	28	69
2	3	23	13	39	18	7	25	19	51
3	5	23	23	51	19	9	14	21	44
4	2	23	23	47	20	5	29	21	55
5	1	22	2	25	21	7	19	24	50
6	2	14	9	25	22	12	13	22	47
7	9	21	4	34	23	10	12	12	34
8	3	28	7	38	24	9	14	23	46
9	22	24	7	53	25	9	11	18	38
10	9	21	7	37	26	8	14	3	25
11	3	12	8	23	27	3	26	8	37
12	14	19	19	52	28	7	21	6	34
13	12	31	9	52	29	1	18	18	37
14	10	10	18	38	30	6	12	14	32
15	7	30	26	63	31	1	31	18	50
16	24	29	50	103					

Total number borers.. 1,375

Table IX shows that in row 16, where the adult females were liberated, the total number of borers for the three years was greater than in any other row of the orchard. It shows also that a few rows on each side of row 16 contained considerably more than the average number of borers for the other rows of the orchard.

In 1915 nine female and several male beetles were liberated on row 29. A later examination showed that this had resulted in the greatest number of borers occurring in row 29, the central rows of the orchard having this year the fewest borers.

The results shown in Table IX and the distribution of the borers found in 1915, when the females were placed on row 29, are set forth graphically in figure 4.

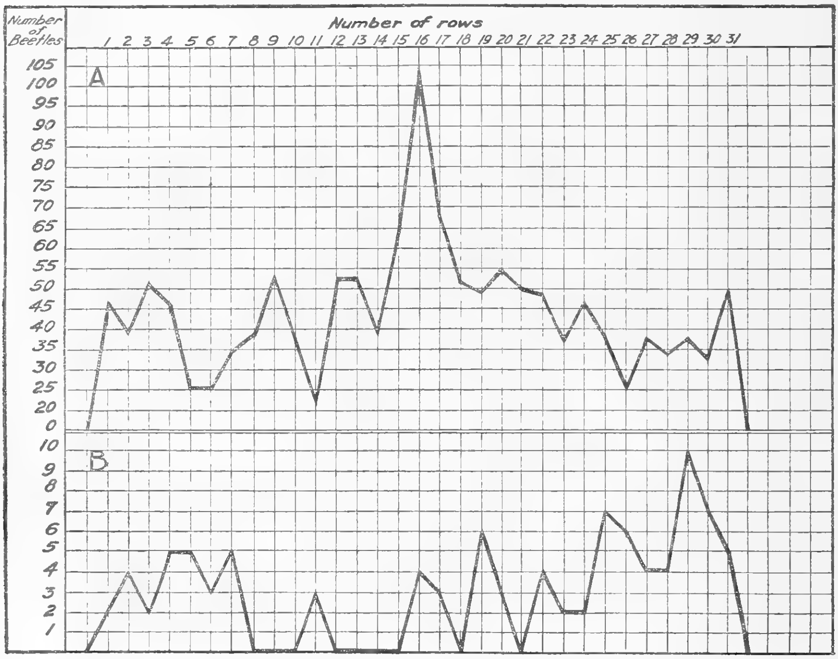


FIG. 4.—*Saperda candida.* Diagram showing tendency of female beetle to refrain from long flights during oviposition. *A*, Number and distribution of borers found in orchard after liberating 124 female beetles during three separate years on row 16. *B*, Number and distribution of borers found after liberating 9 females on row 29.

All the foregoing data on the flight of the female point to a constant tendency on her part to deposit eggs near the place of her development. They also afford good evidence that the female beetle is capable of flights of considerable distance when impelled by any special desire.

In one case when a female was liberated in the manner described above, she immediately took wing and arose to a height of 30 or 40 feet and then disappeared in the direction of a tract of woods about

500 yards distant. That such flights are unusual, however, is indicated by all the evidence that could be gotten.

FEMALES LESS PRECOCIOUS THAN MALES.

The females are not only less active in flight and more sluggish generally than the males but are regularly two or three days behind the males in issuing from their pupal quarters in the wood. This constant tendency on the part of females to be slower than the males in emergence is illustrated by figure 5.

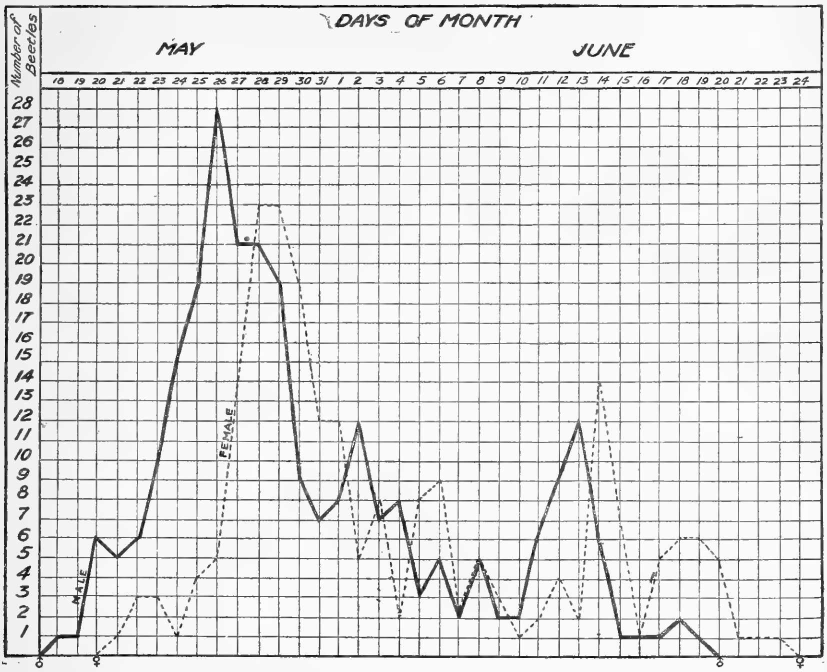


FIG. 5.—*Saperda candida.* Diagram illustrating the relative time of emergence of male and female beetles. Based on 261 males and 206 females that issued under natural conditions at French Creek, W. Va., in 1914, 1915, 1917, and 1918.

SEASONAL PHENOMENA OF THE HOST TREES AS AN INDEX TO THE TIME OF DEVELOPMENTAL CHANGES OF THE INSECT.

Since this borer occurs in North America from southern South Carolina and Texas northward into Canada the calendar dates of its metamorphic changes in different latitudes must vary considerably. There must also be a considerable yearly variation in the dates of these changes in any given locality, due to the early or late advent of spring.

In the rearing work with this species it was found that between Demorest, Ga., and Winthrop, Me., there was a difference in time of emergence of the first beetles of about 40 days. On Grand Island, in northern Michigan, the first beetles appeared 75 days after the date of the first appearance in Georgia. In the several years during which beetles were reared at French Creek, W. Va., there was a variation of 13 days in the dates of the first adults to issue. Calendar dates are therefore of little value in expressing the time when a given metamorphic change of the insect takes place. It was found, however, that the time of certain transformations and activities of the borer may be anticipated or determined very conveniently by observing the definite annual steps in the development of foliage, flowers, and fruit of the apple and other trees upon which the insect lives.

The first blossoms to appear on apple follow closely the first activities of the borers in the spring and it is just in advance of apple blossoming time that the first fresh castings thrown from trees by borers may be looked for. Also, the blooming time of apple corresponds quite definitely with the pupal period of the insect. The oviposition time of the beetles begins with and extends somewhat beyond the ripening season of the fruit of the service tree. These rules hold good in a general way for all latitudes and altitudes and for early and late springs.

The following field notes arranged in Table X indicate the coincidence of these events in a number of different localities:

TABLE X.—*Indicating the correspondence in time of certain developmental changes in the roundheaded apple-tree borer and its host trees.*

Locality.	Date.	Field note.
Frenchton, W. Va	Apr. 27, 1914	Blossoms of York Imperial and Maiden Blush one-half open. One pupa of *S. candida* found.
Weston, W. Va	Apr. 28, 1914	Apple trees in full bloom. More than half the transforming borers have pupated.
Great Cacapon, W. Va	May 5, 1914	Apples a little past full bloom. About 25 fresh pupæ of *S. candida* collected.
Pickens, W. Va	May 20, 1914	Three-fourths the apple petals off. Maturing borers all in pupal stage.
Winthrop, Me	June 22, 1914	Apple blossoms have been off 2 weeks or more. Pupæ of *S. candida* still present. A few have issued.
Gadsden, Ala	Apr. 29, 1915	Apple petals have been off 6 days. One pupa of *S. candida* found.
Demorest, Ga	May 1, 1915	Apple trees just past full bloom. All maturing *S. candida* in pupal stage.
Biltmore, N. C	May 4, 1915	Do.
French Creek, W. Va	Apr. 20, 1916	First apple blossoms opened to-day. Half the transforming borers have pupated.
Do	Apr. 25, 1917	First apple blossoms opened Apr. 22. All maturing borers have pupated Apr. 25.
Do	Apr. 27, 1917	Borers in apple threw out first castings a few days in advance of first apple blossoms.
Munising, Mich	June 20, 1917	First apple blossoms opening. About a dozen fresh pupæ of *S. candida* found.
French Creek, W. Va	Mar. 26, 1918	Apple buds showing first pink. Fresh castings first appearing from 1-year-old borers.
Do	May 15, 1918	Last petals falling from apple. Transforming borers all pupæ except one male which has changed to beetle.
Do	June 13, 1914	First fruit of service ripened May 29. First eggs of *S. candida* June 4. Fruit of service overripe June 13. Egg laying of *S. candida* at height June 13.

NATURAL ENEMIES.

Possibly no other economic insect of equal importance has had so few natural enemies recorded definitely and specifically as has the roundheaded apple-tree borer. In all the literature upon this borer, there seems to be only one original reference to such an enemy, this being the single instance of the hymenopterous parasite *Cenocoelius populator* Say, reared about 30 years ago by Riley and Howard (3, p. 59) from borers of this species received from Indiana. Felt and Joutel (6) state that an undetermined carabid larva was found preying on the borers by Walsh and Riley, and practically all observers have noted that woodpeckers are an important enemy, although in no case is the specific identity of the bird or birds established, so far as the records show.

In rearing and handling many thousands of the borers in various localities the writer has never found any evidence of hymenopterous parasites. In two instances undetermined carabid larvæ were found devouring young borers in West Virginia and another half-grown borer was found that had been killed by a hairworm, sections of the worm being found in the burrow entwined around and within the dead and shriveled body of its host. A large spider was seen to pounce upon and bite in the back a female beetle that had just issued from her exit hole in a tree. In an effort to rescue the beetle the spider was crushed beyond recognition. The beetle died a few hours later from the wound.

WOODPECKERS.

While the control effect of parasites and predacious insects on this borer is negligible, woodpeckers play an important part in holding it in check. Wherever the writer has collected specimens or made observations in borer-infested localities the work of these birds has always been in evidence. Soon after the borers hatch the woodpeckers begin to find them beneath the thin covering of bark and thereafter the birds drill for them as long as they are in the tree. In several orchards where counts were made from 50 to 75 per cent of the borers had been destroyed in this way.

During October, 1915, 24 young borers were collected and planted in furrows gouged out of the wood beneath loosened tongues of bark on the trunk of an apple tree. A week later, when the tree was revisited for the purpose of putting a wire screen around the trunk to protect the borers from birds, woodpeckers had punctured every tongue of bark and removed the borers from beneath. Not one had escaped. In May of the same year, while pupæ were being collected from an orchard, a total of 11 pupal cells were found and from every one the occupant had been removed by woodpeckers. In another case

21 pupal cells were found, 19 of which had been opened by woodpeckers and the insects removed.

During the winter of 1915 the writer had standing near his office window a young apple tree in which there were known to be three borers ready to pupate the following spring. The borers had been protected previously by a wire screen but now the screen was removed. On December 21 a male downy woodpecker, *Dryobates pubescens medianus* (Swains), was observed to alight on the base of the trunk and move about alternately tapping the bark and assuming a listening attitude. Presently, with a few vigorous strokes, it drilled through the bark at the point where the future exit hole of a beetle was to have been and at once drew forth and swallowed a large borer. (Pl. V, B.) A minute or two later it located a second borer, disposed of it in the same way, and then flew away without further search. Again, in January, 1916, the trunk of a young apple tree known to contain full grown borers was planted in a natural position near the same office window. A few days later a pair of downy woodpeckers came to the tree and after a brief search the female was seen to remove and swallow a borer. A little later the male found and removed another. The birds would move about over the trunk tapping lightly with their beaks until the quarters of a borer were located. Then with a few sharp strokes they would penetrate to the burrow and remove and devour the insect. The female bird located and removed her specimen through the partly prepared exit hole in less than a minute, but the male drilled industriously for his nearly five minutes, making during the time several openings into the wood which extended in a line over the burrow made by the borer in ascending the trunk to prepare its pupal chamber.

Other observations were made which indicate that the hairy woodpecker, *Dryobates villosus villosus* (L.), also destroys the borers, but this bird was not seen in the act of removing the insects from the tree.

METHODS OF CONTROL.

Ever since the roundheaded apple-tree borer was first recognized as a serious orchard pest, two principal ways of combating it have been advocated: First, the worming process, in which the borers are removed from their feeding places in the tree by the use of a knife and other tools (Pl. IX, B); and, second, the covering of that portion of the trunk of the tree where the eggs are most frequently laid with some protective wash, paint, or mechanical device which will act as a barrier against the female beetles during oviposition. Both of these methods are commonly practiced in orchards and have been the lines of most frequent and extensive experimentation by investigators of borer injury and control. In the present studies, modifications of these two methods have received special consideration. Tests were made of the effects of penetrating liquids of an irritating or poisonous nature when applied to the bark beneath which borers were feeding, of gaseous and poisonous liquids injected into the burrows, of sticky substances applied to the trunks of trees for the purpose of entangling the adults during their egg-laying activities, and of killing the adults by the use of poisonous sprays. Studies were made also of the distance which female beetles may fly in search of trees in which to oviposit, with the idea of determining the possibility of preventing the infestation of orchards by destroying near-by breeding places. These various tests are described in detail below under their various headings.

WORMING.

The labor of removing borers from trees with a knife and wire is not relished by the majority of orchardists, and yet the difficulties and expense of the task are less than in many other necessary operations in dealing with insect and fungous enemies. Two men, on an average, with an insignificant expenditure for tools and material, should worm 500 trees in a day and obtain as high a percentage of control as ordinarily results from a spraying operation against the codling moth or San Jose scale. Not only does a thorough worming of an orchard rid the trees of the borers present at the particular time but it insures a decreased number of borers for the following one or two years. As is shown on pages 20 to 24, by preventing adult borers from developing within and adjacent to an orchard a reduction may result of about 75 per cent in the number of borers that will attack the orchard the ensuing year.

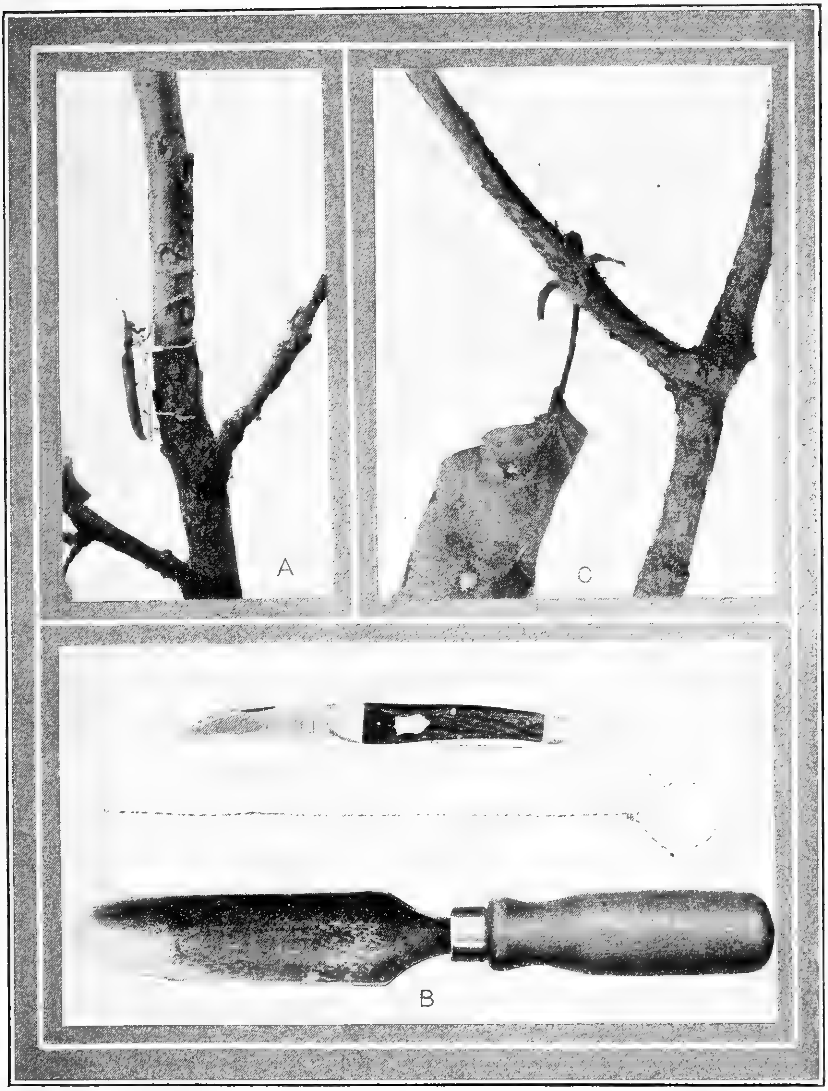
The process of worming is well understood; the best tools for the purpose being a garden trowel for removing the earth and litter about the trees, a pocketknife with a long, sharp blade, a narrow chisel for securing borers that have penetrated deep into the wood, and a piece of slender wire (Pl. IX, B) about a foot in length with a sharp hook bent at one end and a tag or bit of conspicuous cloth attached to the other end to safeguard the wire against loss. These tools may be carried conveniently in a small fruit basket. The writer found that worming can best be done by two men working together on opposite sides of the tree. With a little practice, one becomes quite adept at locating burrows and hooking the borers from their retreats. After a little skill has been acquired the chisel will have to be used only on rare occasions when deep burrows in the wood are found to be so crooked that the wire on being inserted will not follow the openings.

Worming should be done as soon as possible after the last eggs of the year have hatched, as young larvæ usually feed rapidly and often injure small trees severely the first season. The proper time for the autumn worming varies two months or more between the southern and northern limits of the insect's range, and no definite date can be given which applies to all localities. A safe rule is to have the worming job over before the time arrives for gathering the first winter apples. The borers continue to injure the trees during warm weather of late autumn and early winter, often ejecting their castings in the latitude of West Virginia as late as December 1. It is best to prevent all possible injury by getting the worming done previous to the press of apple-picking time. Trees should have a second worming in the spring soon after the blossoming time of the apple, as it is practically impossible to secure all the borers at one examination. Borers are usually easy to locate by their fresh castings soon after apple trees bloom. (Pl. VII, B.)

At present no cheaper or more effective method of combating this borer is known than that of worming. In order to get best results, however, the work in the orchard must be done thoroughly, and near-by breeding places, such as scattering growths or clumps of apple, wild crab, mountain ash, hawthorn, and service trees eliminated either by destroying the trees or by worming. Many orchards are wormed thoroughly every year, and just as regularly beetles developing in adjacent trees fly over the fence and provide annually for other generations of borers. For most effective control, therefore, the worming operation should include not only the orchard but the trees of the locality immediately surrounding the orchard in which borers breed, and the trees should be examined twice annually, first in late summer after the egg-laying season is past and again in the spring after the blossoming time of the apple.

WASHES, PAINTS, AND MECHANICAL PROTECTORS.

Various materials and devices have in the past been applied to the trunks of trees, either to prevent the female beetles from getting at the bark to oviposit or to kill the borers while feeding in the bark or wood. For preventing oviposition protective coverings, either of a liquid or mechanical nature, have been tested, and, for killing the borers, penetrating poisonous or irritating liquids have been recommended. In the present investigations about 50 kinds of washes, paints, and mechanical devices were tested as to their effectiveness in preventing egg laying and for killing the borers within the trees. Many of these materials were homemade or homemixed and many others were commercial products purchased either from the manufacturers or on the market. Nothing in the way of trunk protectors was tested, however, that gave satisfactory results in all cases. Some applications afforded full or a considerable measure of protection against



ROUNDHEADED APPLE-TREE BORER.

A, Beetle gnawing bark from apple branch. B, Tools for use in worming trees. C, Apple branch denuded of bark by beetles.

ovipositing females but could not be applied safely to trees on account of the injury to bark or wood. All degrees of tree injury were obtained, consisting of a slight yellowing and dropping of the leaves, checking of growth, roughing and cracking of the bark, rank growth of water sprouts, and killing outright. Some forms of protectors caused the beetles to lay their eggs higher up the trunk than is the custom, the only apparent advantage in their use being that the resultant borers were easier to get at in the worming process. Some other materials, such as white-lead paint, gave excellent results in certain cases, and in others where the same material was used in the same way, the female beetles bit through the coat of paint and deposited eggs freely in the bark beneath. In practically all cases, the time and expense required to make and apply protectors of this entire class are greater than those called for in the worming operations, and the results in controlling the borers are less satisfactory.

PROTECTORS USED AGAINST OVIPOSITING BEETLES.

Since a large proportion of the eggs of this borer are normally deposited within the bark of a limited space just above the ground, it would seem a simple matter to cover or protect in some way that part of the trunk so as to force ovipositing females to go elsewhere to lay their eggs. A considerable number of such protectors were tried over a series of years in a young apple orchard of a thousand trees planted for experiment purposes at Elkins, W. Va. The orchard was set in rows of 31 trees each, and most of the materials were applied to trees of a single row, leaving the trees of an adjoining row untreated to be used as checks. In every case where paint-like materials were used for more than one year fresh applications were made annually. This was necessary for the reason that the growth of the trees caused all substances to crack and expose areas of the bark. The results of several of these tests are given below in Table XI.

Table XI shows that a considerable measure of control was obtained by most of the protectors used. None, however, was entirely satisfactory in every respect.

In addition to the protecting materials mentioned in Table XI, a large number of others were tested. These included proprietary and commercial products in the form of paints, soaps, tar products, whitewash combinations, viscous substances, nicotine washes, and paper and metal contrivances, all intended to keep the female beetles away from the bark either by offering mechanical barriers or by making approach to the bark so difficult or disagreeable that they would go elsewhere to oviposit. None of these was without objectionable qualities, either from the high cost, injury to trees, or lack of effectiveness in keeping out the borers.

TABLE XI.—*Effects of various protectors applied to the trunks of apple trees to prevent beetles of the roundheaded apple-tree borer from ovipositing in the bark.*

Kind of protector used.	Number of trees treated.	Number of years used.	Number of borers found each year in treated trees.					Total number of borers in treated trees.	Number of borers found each year in check trees.					Total number of borers in check trees.	Per cent borers were reduced by treatment.	Remarks.
			1913	1914	1915	1916	1917		1913	1914	1915	1916	1917			
White lead and boiled linseed oil	31	5	0	4	2	4	2	12	4	7	25	13	10	59	79.7	No injury to trees.
White lead and raw linseed oil	31	5	5	6	3	12	11	37	12	23	5	29	28	97	61.9	Do.
Commercial white-lead paint	31	4		1	0	9	8	18		12	2	48	40	102	82.4	Do.
Axle grease	25	2	0	0				0	9	4				13	100.0	Trees killed.
Gas tar	31	3	8	1	0			9	9	14	25			48	81.3	Trees severely injured.
Soft potash soap	31	3		9	0	8		17		10	2	17		29	41.4	No injury to trees.
Asphaltum	31	4	2	5	0	11		18	4	7	25	13		49	63.3	
Whitewash	31	1	12					12		13				13	.7	Do
Whitewash and glue	31	2			0	20		20			8	24		32	37.5	Do.
Lime-sulphur wash	31	5	5	4	0	16	9	34	8	12	2	48	40	110	69.0	Do.
Tarred-paper wrappers	11	2	0	0				0	1	1				2	100.0	Trees killed.
Burlap wrappers	31	1	9					9	9					9	0	Little injury. Eggs laid above wrappers.
Wire-screen wrappers	31	1	6					6	16					16	62.5	Little injury to trees.
Grass and brush around trunk	25	1	8				8	8					5	5	37.5—	Grass and weeds kept mowed around check trees.
Ground around trunk smooth	31	1					7	7					6	6	14.3—	

A series of tests were made with applications of casein and glue in varying combinations with gypsum, paris white, china clay, sylex, barytes, zinc white, and other pigments, but none of the materials had sufficient lasting qualities to recommend them.

WHITE-LEAD PAINT.

Nothing in the foregoing line of protectors gave better results from every standpoint than white-lead paint. As is shown in Table XI, three forms of this paint were used, one in which the lead was mixed with boiled linseed oil, one with raw linseed oil, and one ready-mixed paint purchased on the market. The first two mixtures were applied annually to 31 trees each for six years and the last to 31 trees for four years. At the end of the periods none of the trees showed any injury, growth being normal and comparable in every way with that of check trees growing in adjacent rows. The total number of borers found during the entire periods of treatment in the trees painted with white lead was 67, the number found in an equal number of check trees during the same period being 258. This shows for the paint a control efficiency of 74.3 per cent.

In one test of paints a large wire-screen cage was built over a clump of 15 4-year-old apple trees in a neglected nursery row. Three of the average-size trees were painted at the base with white-lead paint, 3 with a proprietary tree paint, and 9 were left untreated. As soon as the paint was dry, 7 male and 7 female beetles that had just issued from apple wood were confined in the cage. At the end of the season an examination showed that 193 eggs had been laid by the 7 females, every egg being in the 9 untreated trees, the paints showing 100 per cent efficiency in control. The same season a female beetle that was ready to oviposit was removed from a cage and placed on the trunk of an apple tree in the orchard that had been treated with white-lead paint in the same way as those in the cage. When liberated the female at once crawled up the trunk to a point above the paint, made a slit in the bark, and deposited an egg. She then moved down near to the ground, and, with no apparent difficulty, bit a hole through the paint, made the oviposition slit in the usual way, and placed an egg in the opening. These and other observations showed that the beetles can very easily oviposit through the paint but prefer to place their eggs in the natural bark.

It was very noticeable that some of the borers hatching from eggs deposited beneath a coat of white-lead paint were at first affected deleteriously by the oil which penetrated into the bark. They were slow in getting a start, fed but little, and, in a few cases observed, died within a few weeks after hatching without having made any perceptible growth. Others that were able to burrow deeper into the tissues, beyond the effect of the oil, grew and developed normally.

Considering the ease with which white-lead paint can be procured, the nominal cost of applying it, its noninjurious effect upon the tree, its frequent deterring effect upon the young borers, and its degree of efficiency in preventing oviposition in the tree, the observations of the writer indicate that where protectors of this general class are desired this paint is preferable to other materials. Such paints or protectors as are described above should be applied to the lower portions of the trunks of trees soon after the blossoming time of the apple.

APPLICATIONS FOR KILLING BORERS IN THE TREE.

Various attempts were made to kill the borers, especially while they were young and near the surface, by applying penetrating poisonous and irritating liquids to the bark. With the same object in view, gaseous liquids were also injected into the burrows of larvæ in all stages of development. The details of several of these treatments follow.

NICOTINE SULPHATE.

In September, 1918, 26 apple trees infested with roundheaded apple-tree borers were located, all the burrows opened with a knife, and about a teaspoonful of 40 per cent nicotine sulphate, at a strength of 1 part to 20 parts of water, injected into the opening with a medicine dropper. In all, 67 burrows were treated. An examination made a month later showed that 26 small borers had been killed and 41 of all sizes were alive and active. It was apparent that where the liquid had come into direct contact with the borer death resulted, but where the liquid did not reach the insect no effect was discernible. In another test 29 burrows were treated in a similar manner with 40 per cent nicotine sulphate undiluted. A later examination showed that 21 borers were killed and 8 were uninjured. Of those killed all except one was of small size and all had apparently been doused with the liquid at the time of the application.

In making the opening into the burrow through which to inject the liquid, care had always to be exercised to avoid killing the smaller borers with the knife. The results of the tests showed that this treatment is impracticable. Further data regarding the effect of nicotine sulphate upon the borers when applied to the bark of infested trees are given in Table XII (p. 38).

CARBON DISULPHID.

Tests were made of the practicability of using a veterinary hypodermic syringe and needle for injecting carbon disulphid through the bark into the burrows of the borers. Considerable difficulty was encountered in inserting the needle, and especially in determining when the point of the needle was in proper position for the discharge of the liquid. About 30 burrows were treated in one test and a subsequent examination showed that most of the borers had been killed by the resultant gas. The bark, however, was injured by the treatment. Where the liquid was injected into shallow burrows and came into contact with considerable areas of the inner bark more injury was done the tree than usually results from the direct work of a single borer.

Carbon disulphid can be injected with good results and with no apparent injury to the tree, into burrows that extend deep into the wood. Borers that penetrate beyond the reach of knife and wire can often be killed by discharging a little of the liquid into the open burrow and then plugging the opening with moist clay or some other substance. For injecting the liquid into such galleries, nothing is better than a medicine dropper with a curved point.

KEROSENE.

In September, 1914, 29 apple trees infested with roundheaded apple-tree borers were treated with kerosene, the liquid being applied liberally to the bark with a paintbrush over the regions where the borers were feeding. Four weeks later the trees were examined and 64 borers removed. Of these, 25 were dead and 39 alive. Severe injuries to the cambium and bark were beginning to show. A year later two of the treated trees were dead as a result of the oil application and others had large dead areas near the ground and around the base of the roots.

The conclusions derived from this test were that kerosene applied to the surface does not penetrate through the bark in sufficient quantities to kill all the borers and that its use in this way is dangerous to the health of the tree.

SODIUM ARSENATE WITH MISCIBLE-OIL CARRIER.

Late in the summer of 1918 a 10 per cent solution of sodium arsenate was mixed with a miscible-oil carrier and applied with a spray pump to the trunks of infested apple trees. The treatment was applied to 15 trees that averaged about 4 inches in diameter and contained borers of various ages and sizes. Early during the following spring the borers were removed from the trees, 28 specimens being obtained. Of these, 2 were dead and 26 alive and active. It could not be determined whether the two had died as a result of the treatment or from some other cause, and the treatment was considered of no practical value.

TESTS OF OTHER PENETRATING LIQUIDS.

In the summer and fall of 1917 a number of different penetrating liquids were used on infested apple trees in the experiment orchard at Elkins. The liquids were applied with a paintbrush to the lower portion of the tree trunks as soon as it could be determined that all of the eggs of the season had hatched. The applications were made on August 16 to 17, and the trees examined for results 8 weeks later. The results of the treatments are set forth in Table XII. It should be borne in mind that all the borers considered in the table were newly hatched individuals that were feeding beneath only a thin layer of bark.

TABLE XII.—*Effect upon newly hatched roundheaded apple-tree borers of various liquids applied to the bark over the regions where they were feeding.*

Material used.	Number of trees treated.	Number of borers found— Alive.	Dead.	Total.	Per cent of efficiency.
Nicotine sulphate, 1 part to 10 parts of water	60	26	20	46	43.5
Nicotine sulphate, undiluted	60	13	53	66	80.3
Raw linseed oil	60	22	16	38	42.1
Standard kerosene emulsion	60	28	28	56	50
10 per cent solution sodium arsenate, mixed with equal part of kerosene emulsion	60	15	31	46	67.4

It will be seen from Table XII that many borers may be killed by saturating the bark over where they are feeding with irritants and poisons of a penetrating nature, provided that the treatments are applied while the borers are still small and feeding in shallow burrows. All the materials used in the foregoing test killed a considerable number of borers, the undiluted nicotine sulphate giving best results. None gave complete control, and it is a question whether their use would be justified in orchard practice. Trees so treated would have to be gone over and wormed subsequently in order that entire freedom from borers might be assured.

SPRAYING WITH ARSENATES TO KILL THE ADULTS.

Feeding on the exposed surfaces of the apple and other host trees seems to be a general habit of the beetles. The bark of twigs and leaf stems and the tissues of the leaf are eaten. (Pl. IX, A, C.) Beetles were often observed manducating castings thrown out from the trees by larvæ, evidently for the moisture which the castings contained. The bark and leaf surface eaten away by one female totaled 6.9 square inches. This feeding habit suggests the use of poison sprays as a possible means of killing the beetles. In one small-scale experiment six newly emerged beetles were killed by applying a lead-arsenate spray to the foliage of a small apple tree over which they were caged. All died before the females were ready to oviposit.

In extreme cases of infestation it would probably be profitable to apply arsenical sprays to young apple orchards primarily for the destruction of beetles of this species. Such sprays should be applied about 10 days after the blossoms have disappeared from apple trees and should consist of 4 or 5 pounds of lead arsenate paste to 50 gallons of water, or of the equivalent of this strength prepared with some other insecticidal poison. When trees reach a bearing age, the so-called first codling-moth spray will serve also to kill the beetles of the roundheaded apple-tree borer.

SUMMARY.

The roundheaded apple-tree borer is a native American insect that has been recognized as a serious pest of the apple, pear, and quince since the early days of orcharding in this country.

It occurs in the United States and Canada over most of the apple-growing region east of the Rocky Mountains.

In addition to the cultivated fruits named above, it breeds also in such wild trees as wild crab, hawthorn, mountain ash, and service. These native trees growing in woods or neglected fields often serve as centers in which the adults develop and from which they fly to near-by orchards to deposit their eggs.

In the woods and in orchards the insect is inclined to colonize, families or communities living in the trees of somewhat restricted localities. Often infestation in an orchard or in native woods will be confined for years to rather definite areas or spots. This habit is due largely to the inclination of the adult female to deposit her eggs near the place where she developed.

The common belief that borers of this species prefer to attack trees planted in new ground, in hilly situations, or in certain kinds of soils probably arises from the fact that such situations favor a more abundant growth of the native host trees of the insect. In these wild trees many adults develop and cause serious infestation of adjacent orchards.

About 95 per cent of the eggs from which the borers hatch are deposited in the bark within a few inches of the ground. The incubation period is about 16 days. The borers feed in the bark and wood for from one to four years and finally pupate at the end of an ascending gallery which extends up the trunk from a few inches to approximately 2 feet above the ground.

The burrows made in the bark and wood are broad and irregular in form. Often several borers work close together, as many as 25 or 30 having been found in a single tree. Infested trees become sickly in appearance. They are inclined to bloom freely and set heavy crops of fruit, but often die in an attempt to bring the crop to maturity. Young trees suffer most but trees of all ages are attacked. Trees of an orchard standing near woods are more likely to be injured by borers than those more distant from the woods.

In depositing her eggs the female beetle makes a slit in the bark with her mandibles and then inserts her ovipositor and places the egg between the bark and wood or between layers of the bark. About 9 or 10 minutes are required for the deposition of a single egg. Usually from 2 to 5 eggs are laid at a time. Probably all eggs are deposited by day, and the female in ovipositing shows a slight preference for the sunny or exposed side of the trunk, 65 per cent of the eggs being found in one case on the exposed side of the tree. In the latitude of West Virginia, the average number of eggs deposited by a single female is apparently from 20 to 30. Oviposition in a given locality extends over a period of from 50 to 60 days.

The larvæ begin to feed immediately after hatching and usually grow rapidly the first season. Feeding is continued until cold weather and is resumed again in the spring shortly before the blossoming time of the apple. The larva may spend from one to four years in the tree, this stage being of longer duration in the North than in the South. At French Creek, W. Va., 85 per cent of the larvæ remained in the trees two years before pupation, and 12 per cent three years. At Winthrop, Me., 25 per cent remained in the tree three years and 75 per cent four years.

The pupal stage lasts about 20 days and the period is about coincident with the blossoming time of apple. After changing to beetles the insects remain in the pupal chamber for from 5 to 10 days and then gnaw a circular hole through the bark at the upper end of the chamber and escape. The beetles appear in the South earlier than in the North. Between Demorest, Ga., and Munising, Mich., there was a difference of 75 days in the dates of the emergence of the first beetles. At French Creek, W. Va., beetles issued from the wood during two different years over a period of 30 days. Other years the period was shorter. May 12 was the earliest date for the appearance of a beetle in any year at French Creek, and June 23 was the latest date. A few beetles lived 60 days after issuing.

Pairing may take place at once or may be delayed 10 days after emergence. Eggs are laid soon after pairing. In an apple orchard containing 310 King, 341 Grimes, and 341 York Imperial trees, the Grimes were most severely attacked in four out of five years, nearly 50 per cent of all the eggs being laid in Grimes trees. This could be accounted for in no other way than that the borers showed a preference for this variety.

Experiments showed that the female beetles during oviposition are capable of flying to a considerable distance, but that they prefer to place their eggs in trees near the place where they themselves have developed. By preventing the development of adults in the orchard trees and in other trees growing within from 300 to 600 feet of the orchard, subsequent infestation was reduced 73.6 per cent.

The borers have few insect enemies, but woodpeckers play an important part in holding them in check. The downy woodpecker was observed removing borers from trees.

No easier and cheaper way of controlling borers was found than the old method of worming trees. The worming should be done as soon as possible after the last eggs of the season have hatched, and should be repeated in the spring following the blossoming time of apple trees. Worming can be done most effectively by two men working together on opposite sides of the tree. In this practice emphasis is placed on the importance of removing all breeding centers within or adjacent to the orchard.

Paints and various other kinds of tree protectors were used to prevent the adult females from ovipositing in the bark. Nothing of this nature was found that surpassed common white-lead paint in cheapness, ease of application, and effectiveness in controlling the borers. Young apple trees painted once annually for from four to six years showed no injury and the treatment gave a control efficiency of 74.3 per cent.

Various attempts to kill borers were made by applying to the bark of infested trees penetrating liquids of a poisonous or irritating nature. Nicotine sulphate, kerosene, kerosene emulsion, sodium arsenate in a miscible-oil carrier, and linseed oil were among the materials tested. None of these was effective on large borers that had penetrated deep into the tree, but most of them killed a considerable percentage of young borers that were still feeding in shallow burrows.

The beetles feed rather freely upon leaves and the bark of twigs. Tests made indicate that it is possible to kill the beetles by spraying with arsenicals. Sprays for this purpose should be applied to young orchards within 10 days after apple blossoms have disappeared. In bearing orchards what is known as the first codling-moth spray will be effective also against the adults of the roundheaded apple-tree borer.

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UNITED STATES DEPARTMENT OF AGRICULTURE

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OFFICE OF THE SECRETARY

Contribution from the Office of Farm Management

H. C. TAYLOR, Chief

Washington, D. C. June 22, 1920

AN ECONOMIC STUDY OF SMALL FARMS NEAR WASHINGTON, D. C.

By W. C. FUNK, *Assistant Agriculturist.*

CONTENTS.

INTRODUCTION.

This bulletin presents the results of a study of the organization of small farms in the vicinity of Washington, D. C. Information was obtained regarding the important and outstanding farm practices followed on 152 small farms, and an analysis was made of the business of each of these farms to find out the amount of capital used, the kind and quantity of crops raised, the kind and amount of live stock kept, the nature and volume of receipts, the expenses incurred, the returns realized, and other facts bearing on the organization and operation of these farms.

In this study only those men were interviewed who depended on the returns from their farms as their main source of income. It was an economic study of farming on small areas in which each operator devoted most of his time to labor and supervision on the place. Men who had a regular occupation away from the farm and spent only evenings, holidays, and vacations on their farms were not included, as their work was manifestly not comparable with that of men who worked regularly on the farm and could give close supervision to the different farm operations. Not many colored operators were found in this area and none was interviewed.

The data presented apply to the crop year 1916. The general conditions, as affecting yields of crops and prices, were fairly normal. The effects of the European War were not sufficiently felt at this time to change materially the profits in farming or management of farms in this region.

SUMMARY OF RESULTS.

The small farms visited in this survey were all devoted to trucking or market gardening. Over 50 per cent of their total crop area was devoted to vegetables and fruits, and 90 per cent of the receipts were from this source.

The average labor incomes realized, according to size of farm, were as follows:

Labor incomes.

Number of farms.	Farm area.	Tillable area.	Labor income.
	Acres.	*Acres.*	
45	11	6	$131
57	21	13	223
29	39	23	668
21	57	35	1,147

Land values are high for farming purposes. In most instances 5 per cent of this value exceeds the renting value of the farms. The landlords of the rented farms realized an average of only 2.9 per cent on investment.

Twenty to thirty per cent of the crop area is double-cropped. Labor incomes are materially increased by double-cropping, since thus the same equipment handles more acres of crops than in single-cropping and the production per acre is increased. Double-cropping is equivalent to increasing the average of cropped land. Intensive farming is necessary for success on small farms.

The farm produce is disposed of by hauling it to the city and selling it either at the public market stands (wholesale or retail) or through commission men.

Twenty-four farms, or 16 per cent of those studied, were operated by tenants. Twenty of the tenants paid a cash rent and the other four gave a share of the crops as rent. Thirty-six owners rented additional land and, in general, increased their profits thereby.

DESCRIPTION OF AREA.

Most of the farms visited were located in Prince Georges County, Md., or Fairfax County, Va. A few were in the District of Columbia. The farms in Maryland and Virginia were in the districts close to or adjoining the District of Columbia. The most distant farms were 14 miles from the Washington Center Market. None but small farms were visited.

The basic data for this bulletin apply only to the 152 farms covered in this study.

SOILS AND TOPOGRAPHY.

The predominating type of soil in the Maryland area is Leonardtown loam,[1] with small areas of Windsor sand and Susquehanna gravel. These soils are of the same geological formation. Leonardtown loam is a heavy type of soil and is silty rather than clayey in texture. It is capable of retaining considerable moisture during the entire growing season. Windsor sand is a medium to coarse sandy soil, containing a small amount of fine gravel. This soil is loose and friable and does not hold moisture well. Susquehanna gravel is distinctly stony or gravelly and is unsuited for ordinary farm crops. These two poorer soils usually constitute only a part of the farms in this area. The topography of the region is rolling to hilly.

In the Virginia area the farms were located largely on the Chester loam. soil.[2] This soil is a loam or silty loam that works up easily into a mellow, friable seed bed. It is well drained.

RAINFALL AND TEMPERATURE.

The rainfall for the year 1916 in Washington, D. C., was 38 inches, which was 5 inches less than the average. The rainfall for June and July, however, was above normal for those months. The season was cool, but there was abundant rainfall for the early summer vegetables and fruits. The month of August was dry for the late summer crops. The last killing frost in the spring was on April 11, and the first in the fall on October 1.

KIND OF FARMING.

The main business of the small farmers visited in this survey was raising vegetables and fruits for the local market. (See Table I.) The distribution of receipts, which is shown in a later table, indicates that about 90 per cent of the receipts were from crops.

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[1] Soil Survey of Prince Georges County, Maryland, U. S. Dept. of Agriculture.

[2] Soil Survey of Fairfax and Alexandria counties, Virginia, U. S. Dept. of Agriculture.

TABLE I.—*Average distribution of crop area on 152 small farms near Washington, D. C.*

	Tillable area (per cent of total crop area).			
	10 acres and under	11 to 20 acres.	21 to 30 acres.	Over 30 acres.
Field crops:				
Corn	10.2	6.6	17.3	19.2
Hay	11.4	12.8	17.2	20.6
Grain	.3	.2	4.0	3.7
Total	21.9	19.6	38.5	43.5
Vegetables:				
Potatoes	11.1	13.5	12.1	10.7
Sweet corn	8.9	5.7	7.5	8.6
Tomatoes	6.8	8.1	3.8	4.0
Spinach	2.9	5.1	3.5	2.5
Sweet potatoes	2.8	5.2	2.8	3.1
Turnips	3.5	5.8	2.9	2.1
Kale	3.1	4.8	2.8	2.2
String beans	5.7	3.7	2.4	2.5
Cantaloupe	2.9	3.2	2.1	2.0
Peas	3.5	2.6	1.4	1.1
Cabbage	1.5	2.3	2.2	.7
Lima beans	4.2	2.0	1.2	.7
Lettuce	.9	2.8	2.0	.3
Squash	.7	1.0	.4	.6
Peppers	.7	.5	.6	.5
Radishes	1.2	1.1	.2	.2
Asparagus	.7	1.0	.4	.1
Onions	.7	.7	.3	.5
Beets	.5	.9	.5	.2
Carrots	.5	.8	.6	.1
Cucumbers	.6	.6	.3	.2
Black-eyed peas	.8	.6	.3	.2
Parsnips	.2	.5	.6	(a)
Rhubarb	.2	.5	.3	(a)
Egg plant	.2	.4	.3	.1
Miscellaneous vegetables	2.1	.6	1.1	1.3
Total	66.9	74.0	52.6	44.5
Fruits:				
Strawberries	5.0	2.7	3.0	2.9
Apples	.3	1.0	2.2	3.4
Raspberries	1.5	.9	1.8	1.9
Blackberries	2.5	.8	1.0	.5
Miscellaneous fruits	1.2	.9	.9	3.3
Total	10.5	6.3	8.9	12.0
Flowers, total	.7	.1	(a)	(a)

a Less than 0.1 per cent.

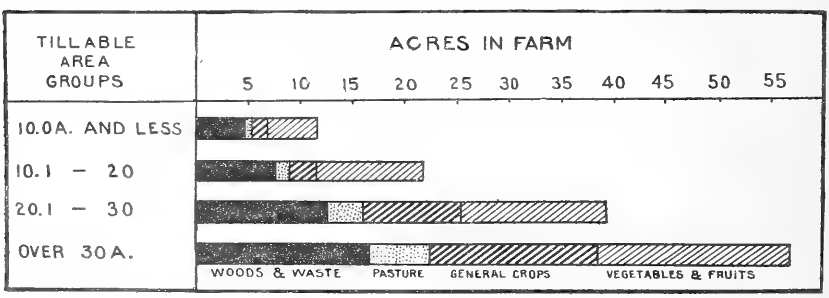

FIG. 1.—Distribution of farm area on 152 small farms near Washington, D. C.

Over 50 per cent of the crop area is devoted to vegetables and fruits (fig. 1). When the farms increase in area the proportion of land used for the general crops—corn, hay, and grain—increases, more of these crops being needed to feed the increased number of horses and other stock on the larger farms, and more land being available for this purpose. On many of the smaller farms no corn or grain is raised, necessitating the buying of feed. With a very limited amount of land available for crops, the farmer finds it more profitable to utilize the greater portion of it for raising crops of

FIG. 2.—View of one of the small, highly intensified truck farms.

high market value and such as will furnish profitable labor for one or more men through the season. (See fig. 2.)

The live stock kept on these farms was practically limited to horses needed for farm work, and to cows, pigs, and chickens kept for the production of food for the family. The sales of live-stock products were negligible, with the exception of those of poultry products. The average flock for these farms was 33 chickens.

No greenhouses for raising vegetables for market were found in this area.

TABLE II.—*Summary of the farm business on 152 small farms near Washington, D. C.*

Item.	Tillable area.			
	10 acres and under. (45 farms.)	11 to 20 acres. (57 farms.)	21 to 30 acres. (29 farms.)	Over 30 acres. (21 farms.)
Farm area.....acres..	11	21	39	57
Crop area.....do....	6	13	23	35
Investment	$2,747	$6,430	$7,451	$8,636
Receipts	$794	$1,651	$2,478	$3,013
Expenses	$526	$1,107	$1,437	$1,434
Farm income	$268	$544	$1,041	$1,579
Interest on investment at 5 per cent	$137	$321	$373	$432
Labor income	$131	$223	$668	$1,147
Value of farmer's labor	$305	$351	$406	$372
Per cent on investment	—1.3	3.0	8.5	14.0
Value unpaid family labor	$88	$54	$34	$34
Family income	$356	$598	$1,075	$1,613
Interest paid on indebtedness	$8	$10	$26	$28
Amount available for family living	$348	$588	$1,049	$1,585
	Months of labor for the year.			
Hired labor	2.9	12.3	19.0	17.6
Operator and his family	15.3	14.0	13.2	13.2

NOTE.—Definitions of terms:

Investment.—The value at the beginning of the farm year of all real estate, machinery, live stock, and other investment used to carry on the farm business. It includes the value of the farm dwelling, but not the household furnishings.

Receipts.—All sales of crops, the net increase from stock, receipts from outside labor, increase of inventory of feed and supplies at end of year, rent of buildings, etc. Farm products retained for personal use are not included.

Expenses.—The amount of money paid out during the year to carry on the farm business, together with the value of the unpaid labor performed by members of the family. Decrease of inventory of feed and supplies at end of year is considered as an expense. Household and personal expenses not included.

Farm income.—The difference between receipts and expenses.

Labor income.—The amount that the farmer has left for his labor after 5 per cent interest on the investment is deducted from the farm income. It represents what he earned as a result of his year's labor after the earning power of his investment has been deducted.

Per cent on investment.—The rate returned on the farm investment after the value of the farmer's labor is deducted from the farm income.

Family income.—The sum of the farm income and value of unpaid family labor, or the amount available for family living had there been no interest to pay.

PROFITS.

In Table II is shown a general financial summary of the farms visited. It will be noticed that the 45 farms having an average crop area of 6 acres have the smallest investment, and that their income is also the lowest. Only five of the farmers of this group made a labor income of over $400. It thus can be seen readily that the chances for making a large income on farms of under 10 acres in this region are not very good. It is the exceptional farmer who can make more than a living on such farms without any outside source of income.

The incomes increase very rapidly with increase in the number of tillable acres available. The second group of farms, having 11 to 20 acres tillable, make an average labor income of $223. Two out of every five farms returned labor incomes of over $400. The farmers in the other two size-groups made labor incomes averaging over $400.

The prospective farmer should study this table carefully. If the farm he has in view falls in the smallest size-group, for example, he need not assume that he can not do better than the average did, as indicated in Table II, since many of these farmers made much more than the average (see fig. 3). He must bear in mind at the same time that it will require the best management and a considerable knowledge of farm practice and markets, and that most of the farm work will have to be done by himself and his family, if he is to succeed on one of these very small farms.

FARM RECEIPTS.

TABLE III.—*Distribution of farm receipts on 152 small farms near Washington, D. C.*

Source of income.	Tillable area.			
	10 acres and under.	11 to 20 acres.	21 to 30 acres.	Over 30 acres.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Vegetables	70.0	83.8	80.3	72.7
Fruits	12.0	7.6	9.5	12.0
Flowers	2.2	.6	....	....
General crops	.1	.2	1.7	2.9
Poultry	4.9	3.5	2.0	3.9
All other stock	.1	.3	.8	2.0
Miscellaneous	10.7	4.0	5.7	6.5

Table III shows the distribution of farm receipts. Over 80 per cent of the receipts are from vegetables and fruits. The live-stock receipts outside of poultry are practically negligible. This table indicates clearly the type of farming followed by these farmers. The comparative importance of miscellaneous receipts for the group of very small farms is due mainly to income from outside sources. Some of the men on these farms do team work, a few work at trades, and still others do ordinary day labor when their farm work is not rushing, though a small proportion of the year is spent at outside work. This additional income is often necessary on very small farms, as the farm receipts are not enough to furnish a living for the family. All farms with outside receipts that exceeded the farm receipts were excluded from consideration in this study. The smaller farms also sell the most flowers and small fruits, thus increasing their business by more intensive production. The farmer with limited acreage must make up for lack of land by raising crops which yield a high return per acre. These crops usually require so much hand labor that the farmer who works many acres will not compete in raising them.

FARM EXPENSES.

In Table IV is shown the relative importance of the different items of expenditure. It will be seen that in the group of very small farms there is a relatively high expense for family labor, which must be charged against the business, whether actually paid for or not. The expense for hired labor is low compared with that for the large farms. In other words, the small business on these little farms would not justify a big expenditure for labor. It should be explained that "family labor" is the farmer's estimate of what he would have paid had he hired some one to do the farm work done by his family.

TABLE IV.—*Distribution of farm expenses on 152 small farms near Washington, D. C.*

Item of expense.	Tillable area.			
	10 acres and under.	11 to 20 acres.	21 to 30 acres.	Over 30 acres.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Hired labor	15.4	32.9	39.7	38.0
Family labor	16.7	4.9	2.4	2.4
Feed	24.5	17.9	11.1	10.0
Seed	5.4	4.4	4.4	5.0
Fertilizer and manure	4.0	6.3	8.7	7.6
Marketing and commission	11.0	14.0	15.3	16.6
Repairs and depreciation	13.8	9.8	10.2	11.3
Insurance and taxes	4.3	5.4	3.8	3.7
Miscellaneous	4.9	4.4	4.4	5.4

The man on the small farm has to buy much of his stock feed. He usually lives in a region of small farms, where most of his neighbors are also truckers, and he is forced to buy most of his feed from feed stores rather than directly from farmers, and thus has to pay dealer's prices. He has not enough land to produce the more cheaply-raised feeds such as hay, corn, and corn fodder.

In studying Table IV as a whole it will be noticed that the larger farms are spending relatively more money than the others for labor, fertilizer, and marketing, and less for feed. In other words, they are paying out the most for the three big items of farm expenses, which on truck farms indicate greater production.

CAPITAL.

TABLE V.—*Average distribution of capital per farm on 152 small farms near Washington, D. C.*

	Tillable area.			
	10 acres and under.	11 to 20 acres.	21 to 30 acres.	Over 30 acres.
Real estate	$2,434	$5,830	$6,506	$7,397
Dwelling	638	861	1,076	1,458
Other buildings	131	300	593	648
Live stock	144	262	422	601
Machinery	97	188	266	248
Feed and seed on hand	15	34	99	171
Cash to run farm	57	116	158	219
Total capital	2,747	6,430	7,451	8,636
Renting value of farm	134	208	212	297

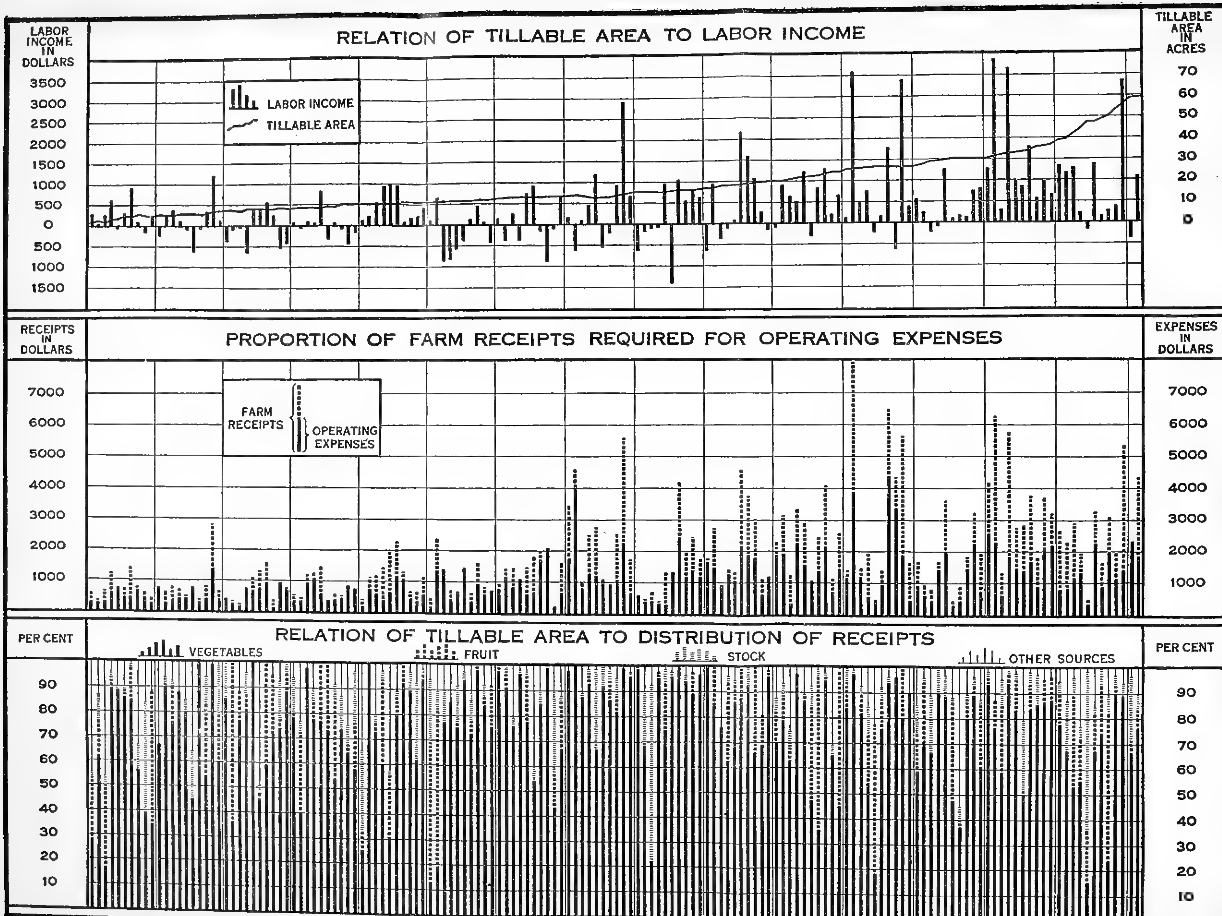

FIG. 3.—Relation of tillable area to labor income, proportion of farm receipts required for operating expenses, and relation of tillable area to distribution of receipts, by individual farms (152 small farms near Washington, D. C.). Each line represents one farm.

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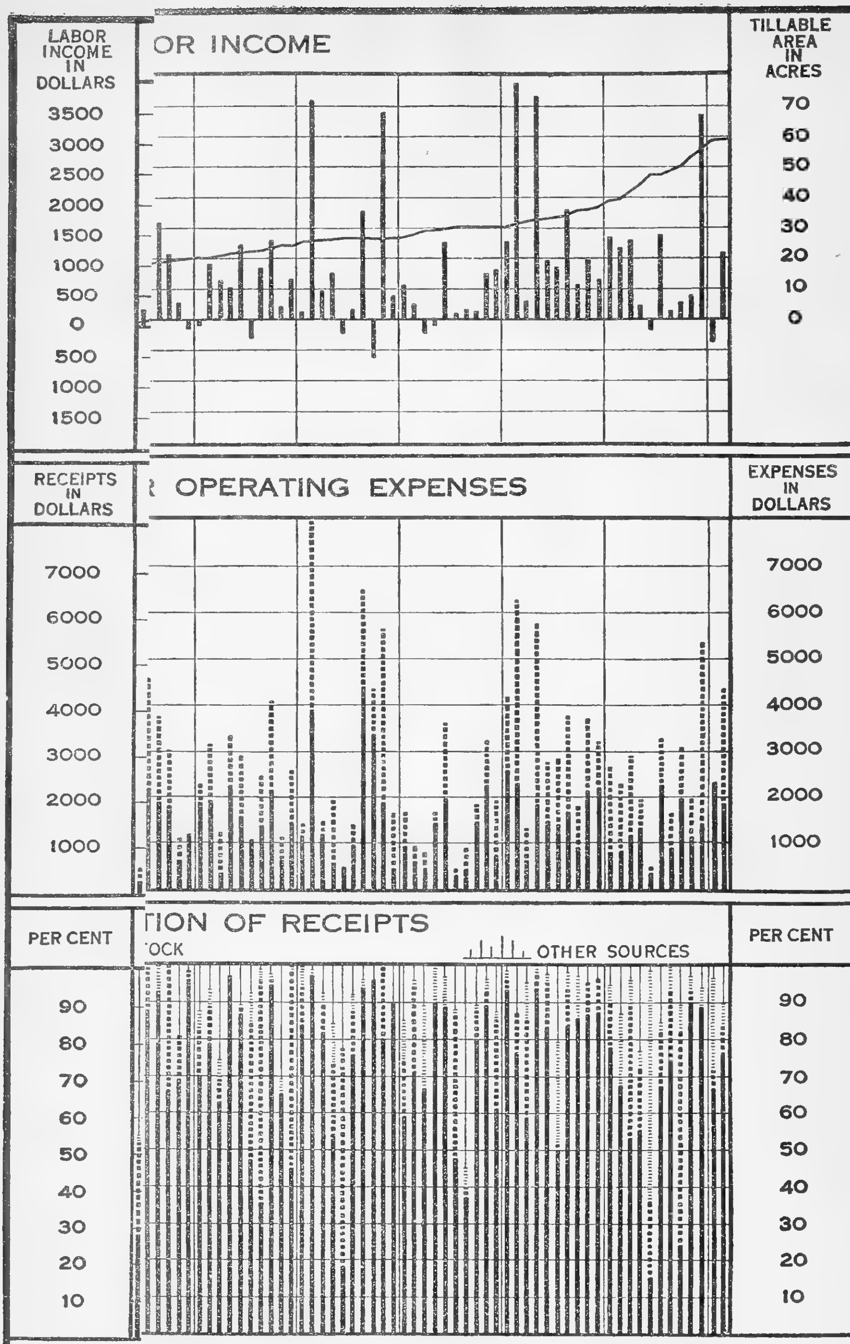

FIG. 3.—Rela| relation of tillable area to distribution of receipts, by individual farms (152
sents one farm.

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In Table V is shown the distribution of capital used in the operation of these farms. Nearly 90 per cent of the total capital is in real estate. The live-stock and machinery investment is low per farm and the value per acre of the farms relatively high. The farms are located close to the city, giving them, in some instances, valuations which are greater than they would be were it not for the influence of suburban real estate values. This speculative factor very often controls the real estate values of small farms located conveniently to market. To determine the effect of this factor for the farms studied, the renting value for farming purposes of each farm was determined. It will be noticed (Table V) that for the smallest farms the renting value approaches very nearly 5 per cent interest on the real estate value. This is probably due to the fact that these small farms are worth very nearly $234 a year merely as a home for the family of a man working in the city. On the larger farms 5 per cent on the real estate investment is nearly $100 greater per year than the annual cash rent for farming purposes.

COMPARISON OF INDIVIDUAL FARMS.

In the previous paragraphs it is shown that in studying groups of farms the labor incomes, on the average, are greater on the large farms. This, however, does not hold true uniformly when individual farms are considered, as is shown in figure 3 and Table VI. There are some farms with good incomes and some with poor incomes in each size-group. The size of farm has an important bearing on the chances of success in farming, but other factors, such as good crop yields, good prices for farm produce, and suitable equipment, which may be grouped under the heading of good quality of business, may more than overbalance unfavorable size of farm. These individual variations emphasize the fact that the men who rank as conspicuously successful farmers rank far above the average in quality of business. The farmer who is content to be merely as good as the average need not hope to be classed among the more successful operators of his community.

TABLE VI.—*Tillable area, labor income, capital, receipts, expenses and distribution of receipts for each of 152 farms near Washington, D. C.*

[Farms arranged according to size of labor income.]

Labor income.	Tillable area.	Investment.		Receipts.	Expenses.	Per cent of receipts from—			
		Real estate.	Other.			Vegetables.	Fruits.	Stock.	Other sources.
$3,805	30.5	$2,000	$721	$6,244	$2,303	76	12	....	12
3,654	32	5,500	807	5,789	1,820	93	5	1	1
3,584	25	8,000	1,789	7,940	3,867	98	....	1	1
3,534	56	6,000	1,156	5,330	1,438	89	....	4	7
3,342	26.3	7,000	1,346	5,614	1,855	80	20	....	....
2,931	14.5	6,000	1,138	5,546	2,258	99	....	....	1
2,194	18	3,300	715	4,578	2,183	88	11	....	1

TABLE VI.—*Tillable area, labor income, capital, receipts, etc.*—Continued.

Labor income.	Tillable area.	Investment.		Receipts.	Expenses.	Proportion of receipts from—			
		Real estate.	Other.			Vegetables.	Fruits.	Stock.	Other sources.
$1,785	33.5	$6,000	$1,083	$3,753	$1,614	84	9	6	1
1,740	26	5,200	1,914	5,494	4,398	93		2	5
1,590	18.62	5,000	1,595	3,773	1,853	92		8	
1,566	59	16,700	2,279	4,390	1,875	77	8	5	10
1,436	39.25	8,000	1,084	2,664	774	78	12	4	6
1,362	48	2,400	726	3,270	1,752	78	13	2	7
1,273	42	8,000	1,216	2,894	1,160	52	37	7	4
1,271	23	12,000	1,263	4,061	2,127	94	1	2	3
1,266	30	5,500	1,170	4,148	2,548	93	2	3	2
1,234	29.5	5,000	1,261	3,531	1,984	89		8	3
1,216	13	5,900	977	2,757	1,197	68		31	1
1,213	21.5	3,250	1,151	2,977	1,544	87	1	1	11
1,206	6.4	5,000	611	2,791	1,304	99		1	
1,120	39.5	6,200	1,154	2,276	788	68		19	13
1,056	19	2,100	631	2,974	1,781	66	34		
1,008	15.5	13,600	757	4,191	2,465	100			
998	10	5,000	868	1,917	626	31	24	2	43
984	36	10,000	1,340	3,680	2,129	87	8		5
971	17	5,400	554	2,739	1,470	85	15		
965	32.5	5,445	1,638	2,809	1,490	83	11	3	3
955	15	1,500	207	1,322	282	73	22	5	
951	10	2,200	335	1,419	341	60	33	3	4
918	10.2	2,500	600	2,253	1,150	80	7	2	11
928	12	4,500	293	1,784	616	53		7	40
923	14.1	1,400	646	2,057	1,032	82	6	7	5
920	3.5	1,200	358	1,486	488	84	13	2	1
897	20	4,800	1,045	3,128	1,939	79	10	4	7
847	32.8	10,000	1,620	2,867	1,439	50	1	28	21
835	22	3,500	1,401	2,469	1,389	36	59	4	1
816	9	1,000	374	1,445	560	76	23		1
802	16	4,000	1,260	2,418	1,353	89	8		3
800	30	6,500	931	1,855	683	61	24	1	14
767	30	3,500	1,064	3,227	2,232	89	3	3	5
762	25.4	2,500	638	1,431	512	54	19	10	17
716	12	2,000	309	1,403	572	78	17	1	4
675	23.5	7,500	758	2,521	1,433	44	55	1	
658	10.5	6,000	827	2,317	1,318	19	73	8	
651	14.8	8,000	634	1,719	636	96		1	3
645	20.4	3,400	307	1,173	343	62	7	5	26
644	12.5	5,000	277	1,554	646	67	19	1	13
609	37	6,000	1,162	3,152	2,185	88	9		3
604	2.8	400	152	1,244	612	89	3	2	6
575	8	1,100	266	1,565	922	59	40		1
531	16	5,000	688	1,963	1,148	92		2	6
513	35.3	5,500	1,022	1,727	888	86		11	3
509	27	3,100	542	1,624	933	59	16	10	15
507	10	2,000	503	1,158	526	73	2	4	21
502	21	10,000	1,832	3,363	2,269	97			3
483	25.35	4,500	1,278	1,890	1,118	81	9	1	9
475	13	14,000	871	2,495	1,276	93	5	1	1
453	11	2,500	421	1,539	940	98	2		
417	10.4	1,710	434	1,084	560	94	1	1	4
387	8	3,500	493	1,317	730	45	1	4	50
383	5	1,000	164	811	370	76	14	2	8
366	26.5	15,000	988	1,579	414	90			10
362	8	1,445	116	1,079	639	100			
343	6.4	1,200	416	833	409	54	29	10	7
336	53	10,000	1,198	1,972	1,076	90	3	3	4
314	32	7,100	1,250	1,252	520	59	26	10	5
286	19.5	3,500	382	1,075	595	69	11		20
269	50	15,000	1,366	3,081	1,994	24	58	8	10
258	3.5	1,150	200	732	406	85	2	1	12
252	11.75	5,300	794	1,422	865	76		2	22
229	5	1,500	259	598	281	90		3	7
225	1.7	1,300	174	527	228	28	27	1	44
225	10	2,500	383	1,081	712	100			
223	1.82	2,000	345	630	290	62	33	4	1
217	4.5	600	116	456	203	34	52		14
211	8.1	1,100	203	386	110	72	23		5
210	28	2,310	610	902	546	71	24	1	4
208	44	4,000	1,306	1,944	1,471	55	17	4	24
202	10.4	750	477	597	334	61		30	9
168	23.2	4,670	534	1,098	670	64		4	32
156	26	5,500	674	1,414	949	76	11	4	9
143	12.75	9,800	557	2,446	1,785	98			2
133	16.2	7,000	782	1,647	1,125	96			4
132	10.4	1,500	303	649	427	89		8	3
120	30	5,000	1,154	1,872	1,444	80	7	2	11

TABLE VI.—*Tillable area, labor income, capital, receipts, etc.*—Continued.

Labor income.	Tillable area.	Investment.		Receipts.	Expenses.	Proportion of receipts from—			
		Real estate.	Other.			Vegetables.	Fruits.	Stock.	Other sources.
$116	49	$10,000	$2,053	$1,599	$880	73	19	8	......
103	6.5	2,500	347	601	356	60	19	20	1
102	11.5	1,140	409	882	703	98	2	......	......
92	11	2,500	396	608	371	72	4	13	11
89	10	3,000	428	465	205	25	7	32	36
83	25	2,500	627	1,353	1,114	83	11	6	......
79	8.8	3,000	413	1,190	940	98	......	......	2
67	5.3	4,000	511	691	398	88	......	......	12
59	18	3,025	531	1,283	1,046	86	6	1	7
59	13	3,600	573	994	726	87	......	3	10
56	8.5	3,000	308	533	312	78	1	15	6
53	30	8,000	719	896	407	37	3	4	56
53	10.3	3,000	546	1,285	1,055	92	8	......	......
52	9.5	1,500	352	560	415	53	34	4	9
49	30	2,500	242	393	207	48	38	......	14
41	10.5	3,000	287	449	244	13	55	25	7
32	9	2,800	539	1,246	1,047	77	7	6	10
29	1.77	900	209	331	247	62	14	10	14
17	11.3	4,000	545	799	555	83	4	4	9
3	4.4	1,200	319	743	664	56	......	11	33
— 28	7	700	146	209	195	76	12	......	12
— 35	6	800	144	309	297	100	......	......	......
— 38	8.8	3,240	173	443	310	40	31	4	25
— 42	5.5	2,000	118	464	400	79	1	5	15
— 50	15	1,200	315	373	347	96	2	......	2
— 50	29.5	5,000	807	1,642	1,402	90	......	9	1
— 50	3	700	78	734	745	88	......	2	10
— 61	12.5	1,400	188	212	194	42	15	28	15
— 73	15	5,500	789	640	399	22	......	70	8
— 77	18	3,250	560	1,344	1,231	62	36	1	1
— 85	7	3,000	283	318	239	36	63	......	1
— 96	10	3,500	262	554	462	74	......	13	13
— 97	20	10,000	343	2,261	1,841	70	12	5	13
— 126	19.75	2,000	874	1,174	1,156	97	2	......	1
— 134	10	1,000	97	633	712	58	19	23	......
— 142	15	3,125	229	423	397	68	......	21	11
— 168	4.5	6,000	454	568	413	39	1	43	17
— 177	12.1	7,460	970	2,000	1,755	84	......	6	10
— 199	48	6,000	631	455	322	16	20	53	11
— 204	13.5	3,100	609	910	929	86	7	6	1
— 209	25.5	1,000	312	350	493	18	59	......	23
— 215	28.9	10,000	663	790	472	67	......	21	12
— 223	4.6	2,000	354	649	754	67	......	......	33
— 304	9.3	775	225	105	359	73	27	......	......
— 335	22	4,500	557	943	1,025	48	35	8	9
— 337	12	4,900	621	963	1,024	97	......	1	2
— 347	11.7	12,000	258	1,381	1,115	91	7	2	......
— 386	7	4,500	173	237	389	85	......	15	......
— 392	18	2,000	564	672	936	76	......	......	24
— 397	59	5,500	1,203	2,249	2,311	67	4	27	2
— 405	11	2,650	370	1,196	1,450	94	......	3	3
— 408	8.5	1,000	225	422	769	88	9	3	......
— 452	11.4	8,000	278	653	691	75	16	......	9
— 482	10	2,000	220	469	840	64	2	9	25
— 533	8.5	6,200	392	790	993	74	3	15	8
— 554	13.3	1,380	669	610	1,062	92	......	8	......
— 580	11	10,000	597	634	684	75	1	15	9
— 613	8	8,000	365	535	730	81	6	10	3
— 620	17	12,600	651	1,716	1,673	100	......	......	......
— 626	13	20,000	2,014	4,529	4,054	100	......	......	......
— 634	15	7,200	463	309	560	99	......	1	......
— 634	5.75	7,000	628	500	753	44	......	20	36
— 638	26.25	32,250	855	4,333	3,316	96	......	......	4
— 809	12.5	15,000	322	1,985	2,028	99	......	1	......
— 837	11	4,200	290	788	1,401	77	......	13	10
— 840	11	21,000	263	700	477	85	......	......	15
—1,406	15.5	22,000	517	1,046	1,326	96	......	1	3

TRUCK-CROP YIELDS.

Below are shown the average yields per acre of the important truck crops on the 152 farms (season of 1916). No direct relation was found between the acreage yields and size of farms.

The 11-peck barrel is standard throughout. The tomato box, squash crate, and cantaloupe crate hold 4 pecks each. The berry crates hold 32 quarts.

Average yields per acre of truck crops.

Irish potatoes	barrels	40	Peas	barrels	23
Sweet potatoes	do	45	Kale	do	41
Sweet corn	dozens	381	Spinach	do	70
Tomatoes	boxes	152	Squash	crates	190
Lima beans	quarts	1,172	Cantaloupe	do	112
String beans	barrels	37	Strawberries	do	69
Cabbage	do	116	Blackberries	do	46
Carrots	bunches	10,902	Raspberries	do	37
Beets	do	7,960			

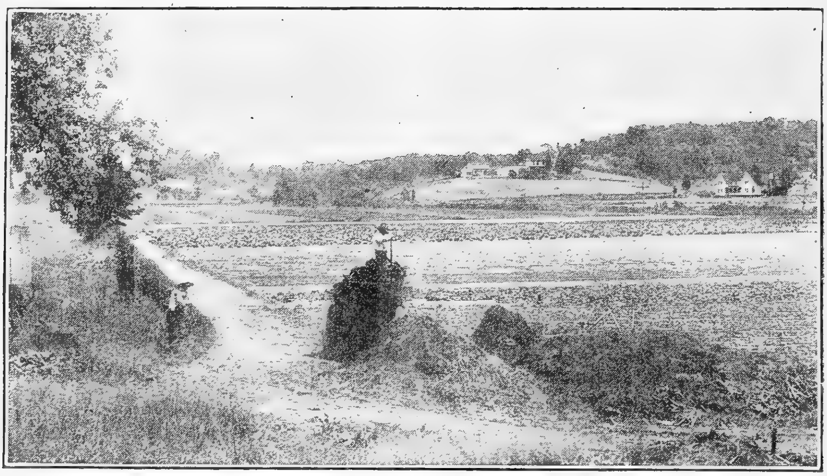

FIG. 4.—Stable manure brought from the city is dumped on compost heap.

MAINTAINING SOIL FERTILITY.

On small truck farms it is not possible to keep up the fertility of the soil by keeping live stock, as on general and dairy farms. The common method of keeping up the yields of crops on these farms is by the use of purchased barnyard manures and commercial fertilizer. About three-fifths of the expenditure for manure and fertilizer is for fertilizer, and two-fifths for manure. Much manure, however, is used for which no money is paid. Many farmers haul it from stables in Washington, where they get it for taking it away. Often after taking a load of produce to the Washington market the farmer will bring back a load of manure for his compost heap. Some farmers contract for all the manure produced at a stable, in which case it is necessary to make one or more trips every week for manure alone. The manure is usually put on a large pile, from which it is drawn in to the field as needed (fig. 4). The actual value of manure used is probably greater than that of the fertilizer used. The supply of stable manure in the city is limited, however, and some farmers are unable to get the required amount.

The importance of maintaining enough humus in the soil is appreciated by all the experienced farmers. Barnyard manure is their chief reliance for this purpose, though rye, crimson clover, or cowpeas are sown occasionally, to be plowed under as green manures. The growing of winter cover crops could be practiced to good advantage much more commonly. Most of the crops grown on these farms are cultivated throughout the summer, furnishing an excellent seedbed in the fall for rye or some winter legume to be plowed under the following spring. Such crops furnish considerable humus to the soil, which the trucker finds it increasingly difficult to supply, and also tend to prevent serious washing of the soil in the spring. The winter cover crop should be plowed under while the stems are still succulent, and the land then very thoroughly worked before the truck crop is planted.

INCREASING ACREAGE BY DOUBLE-CROPPING.

Much of the crop land on these farms is double-cropped. The farmers with 20 acres and under of tillable area raise two crops during the year on about 30 per cent of their crop land, and those with over 20 acres of tillable area raise two crops on about 20 per cent of their crop land. This is a profitable method of increasing the crop acreage on small farms. The above-mentioned two groups of farms were subdivided into two groups each, those double-cropped on less than 25 per cent of their crop area, and those double-cropped 25 per cent and over of their crop area. The labor incomes of the farmers in the first group were $89 for those double-cropping less than 25 per cent of their crop area and $295 for the rest, while in the second group the labor incomes were, respectively, $658 and $1,162.

The importance of having crops growing all the time can not be overemphasized. Many truck crops require only a portion of the season for reaching maturity. *If it is not possible to follow or precede the short-growing crop with another truck crop, a winter cover crop or summer legume should be sown, to be plowed under to improve the soil.*

The number of acres double-cropped also materially affects efficiency in the use of horses. The crops worked per horse for the above-mentioned groups as subdivided on double-cropping were 5.9 acres for those in the first group who double-cropped less than 25 per cent of their crop area, and 9.1 for the rest, and 10.7 and 12.7 acres, respectively, for those in the second group. The efficient employment of horses is very important on these small farms, where more horse feed is usually bought than on the larger, general crop farms. The renting value of the farm and investment in machinery and tools are also made less per acre of crops when double-cropping is increased.

Early peas or early potatoes may be followed by string beans, late potatoes, turnips, spinach, kale, or radishes. Winter or spring grains, if cut for hay, may also be followed by these crops. Winter cover crops should be plowed under just before they head out, and, after being thoroughly worked into the soil, may be followed by any crop normally planted after the last spring frost. Many other successions might be suggested, but each farmer must plan to suit his own conditions. The point is to plan for high production per acre.

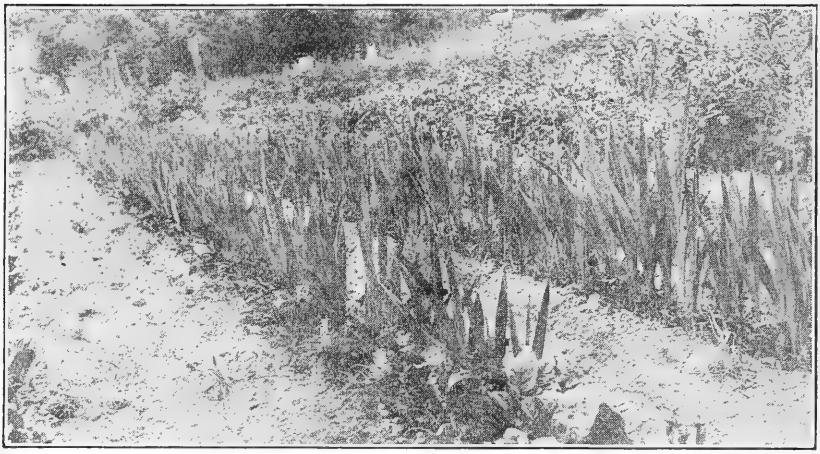

FIG. 5.—Beets and gladioli in same row, permitting use of horse cultivator in intercropping.

Intercropping is often practiced to good advantage. Late vegetables may be planted between the rows of earlier vegetables, allowing the late crop to grow while the earlier ones are maturing. One example was found of planting early and late maturing plants in the same row (fig. 5) allowing for horse cultivation.

In this connection it should be pointed out that over two-fifths of the farms visited had less than half their farm areas in crops, the remainder being woodland, scrub land, waste land, and a negligible part in pasture. The half of the farm in crops had to pay interest and taxes on the other nonproductive half. As the tillable area decreases in proportion to the total farm area, the business becomes smaller and in addition is increasingly burdened with idle capital. When all the farms having 30 acres and under of tillable land are sorted into two groups, those in which the tillable area is 60 per cent and less of the farm area and those in which it is over 60 per cent of the farm area, it is found that the former group returned an average labor income of $73 and the latter an average of $468. Obviously, on such small, high-priced farms the amount of waste land should be reduced to a minimum.

MACHINERY AND TOOLS.

But one-third of the farmers with 10 tillable acres and under have more than one horse. The equipment on these farms usually consists of a one-horse wagon, a one-horse plow, a spike-tooth harrow, a one-horse cultivator, a work harness, and necessary hand tools. Each of these farms also reported 17 hotbed sash on an average. (See fig. 6.)

FIG. 6.—Tomato plants in hotbeds. Board fence gives protection from cold winds.

The large farm usually had both a two-horse and a one-horse wagon. The number of cultivating tools increases with the size of farm, occasionally including a disk harrow or spring-tooth harrow. About half of the farmers have mowing machines. The number of hotbed sash increases with acreage up to a certain point, the greatest number being found on the farms of 11 to 20 tillable acres, averaging 50 per farm.

It is very evident that the operators of the very small farms are at a disadvantage in not having enough land to keep two horses busy, thus necessitating the use of one-horse tools, which waste man labor. When plowing and harrowing and all hauling must be done with one horse, the farmer is manifestly not using his time to best advantage. Much farm labor, to be done economically, requires the use of at least a two-horse equipment.

Two-thirds of the farmers visited had hotbeds for starting early tomatoes, early cabbage, eggplant, peppers, and other early crops.

An early crop usually commands a good price, and the land on which it is grown may be used for growing another crop the same season. Hotbeds are sometimes profitably utilized for growing lettuce very early in the spring and very late in the fall.

MARKETING THE PRODUCE.

Marketing the produce is really a part of the regular farm operations on these farms. The work on the farm is so arranged as to allow the required number of men and horses to deliver the vegetables and fruits regularly to the open market in Washington. A short discussion of this subject thus seems warranted in connection with the study of the management of these farms.

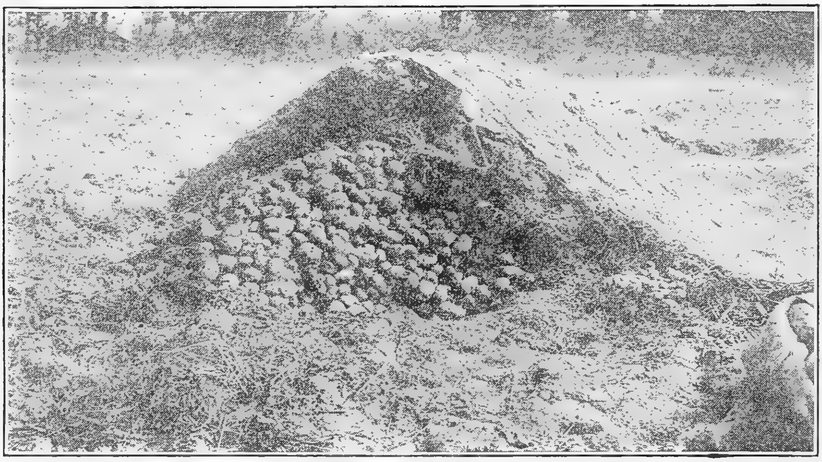

Fig. 7.—Potatoes buried in pit covered with straw and earth. The potatoes were buried in October, and the picture was taken the following May.

Most of the vegetables and fruits raised are of perishable nature and must be marketed when harvested. Irish potatoes are sometimes stored to be held for a better price or a more convenient time of marketing. They are put in cellars or buried in pits. (See fig. 7.)

The produce of all the farms visited was sold on the Washington market. A very few farmers hire their produce hauled and pay a definite commission for hauling and selling. The common practice for the farmer is to do the hauling himself with his farm horses and wagons. The men on the larger farms are beginning to use motor trucks. The average haul to the market for all farms is 9 miles, and the average number of trips to market for all farmers was about 75 a year, the number of trips varying with the quantity and variety of produce grown.

The farmers sell by wholesale, retail, or commission. The city of Washington has a wholesale market which opens at 3 o'clock every weekday morning. Most of the farmers are there by that time. The produce is sold mostly between 3 and 7 a. m. If the farmer has not sold out by 7 o'clock he generally has to sell at a sacrifice. The buyers, retailers, hotel men, boarding-house keepers, or brokers haul the produce away from the farmers' wagons. The farmer who wholesales is usually home on the farm by noon.

Those who retail sell on retail markets, which are separate from the wholesale market. They sell direct to the consumer, and this process usually occupies the greater part of the day. It is generally the farmer with a small acreage of crops who sells on the retail market. The farmer with a big acreage can not dispose of all his produce in this manner.

The grower who sells by commission also delivers his produce to the city, but the commission man does the selling. The grower may return home immediately upon unloading, provided he does not have to wait for the containers, which the farmer is supposed to get, regardless of the method of selling. The usual commission is 10 per cent of gross sales.

Thus it can be seen that marketing is no small part of the operation of these farms. Table IV shows that from 11 to 16 per cent of the farm expenses are for marketing. This is about 10 per cent of the gross crop sales. It includes only the actual cash expenditures incurred in marketing, such as market-stand fees, lunch, and horse feed, and does not account for the time of men and teams required to haul produce to market. Here, again, the farmer who has but one horse is at a disadvantage. He can not haul more than the one horse can draw. He is hauling and selling a one-horse load while he could just as easily sell a two-horse load.

In grouping farms of the same size according to the average price received for their produce, it appears that the farmers receiving the highest prices also get the highest labor incomes. The better prices are partly due to better marketing methods, and reflect better quality of produce, better pack, and having the produce ready early in the season. The trucker, therefore, should aim to raise a crop above the average in quality as well as quantity, and to get it on the market before the bulk of the crop for the section is marketed.

FARM PRODUCTS RETAINED FOR HOME USE.

In a discussion of profits on small farms something should be said regarding the relative importance of farm products retained for home use. The results of this study indicate that the family on the small farm does not get as much food directly from the farm as does the family on the larger farm. For instance, the families having no cow, and therefore having to buy all the milk and butter used, included three-fourths of the families on the smallest farms, one-half of those in the second size-group, and one-fourth of the families on the 21 to 30 acre tillable area. The size of poultry flocks was larger on the larger farms and the consumption of home-produced poultry and eggs was also greater on those farms. The average consumption of home-produced pork for family use was 223 pounds on the farms of 10 tillable acres and under, and 447 pounds per family on the farms of 21 to 30 acres. No attempt was made to determine the quantity of fruits and vegetables kept for home use, but a great variety of these are raised on all farms and the variation in home consumption on different-sized farms was probably not great.

To the family moving from the city to a small farm the farm products furnished directly by the farm may seem very important, but comparing them to the value of those usually furnished on the larger farm, they are relatively unimportant. The man on the small farm usually specializes in production and often does not find it profitable to keep a cow, chickens, and pigs, for raising food for home consumption only. On larger farms these stock are more often kept as regular farm enterprises, making much more meat and other animal products available for home use.

TENURE.

Table VII shows the relation of tenure to profits and type of farming. Only 16 per cent of the farms studied were operated by tenants. Twenty of the tenants paid a cash rent, and four gave a share of the crops as rent. The share was usually one-half of the crops, the landlord paying one-half of the expenditure for seeds and fertilizer, and all the taxes, insurance, and repairs on buildings.

TABLE VII.—*Relation of tenure to type of farming and profits on 152 small farms near Washington, D. C.*

	Owners.	Owners renting additional land.	Rented farms.	
			Tenants.	Landlords.
Number of farms	92	36	24	....
Tillable area, acres	18.3	20.5	13.6	....
Acres of crops	18.9	23.0	16.6	....
Per cent crop receipts are of total receipts	89	89	96	....
Capital	$5,633	$4,475	$464	$5,222
Farm income [1]	$666	$845	$405	$152
Interest on investment [2]	5.8	11.3	25.0	2.9

[1] *Farm income:* Receipts less expenses.
[2] Percentage farm income less value of farmer's labor is of the investment.

The type of farming followed by the renters is very clearly indicated by the fact that 96 per cent of receipts are from crops. The average rent paid for the 24 farms was $162 a year. It is to the advantage of the tenant to raise as much as possible, since he must pay his rent before he can pay himself.

In a comparison of owners we find that those who rented additional land operated more land with a given amount of capital than those who did not. In a region where land values are high because of city speculative values, it may pay better to rent than to buy additional land in order to increase the farm business. It will be noticed that the landlords made only 2.9 per cent on their investment—another indication of the advantage of renting additional land. The farmer with sufficient capital to buy naturally prefers to own his place, but if the place is small he should not hesitate to rent additional land, if possible, in order to increase his profits.

The tenants required a relatively small amount of capital. The farm income of the tenants is less than that of the owners, but if the interest on the capital invested is deducted the net income or labor income is about the same for both groups. The prospective farmer with the necessary experience but with little capital can do better by renting than by buying until he can afford to get a farm of sufficient size for profitable operation.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 849

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief

Washington, D. C. ▼ July 16, 1920

CITY MILK PLANTS: CONSTRUCTION AND ARRANGEMENT.

By ERNEST KELLY and CLARENCE E. CLEMENT, *Dairy Division.*

CONTENTS.

STATEMENT OF PRESENT CONDITIONS.

The market-milk industry has assumed enormous size and importance. By market milk is meant milk consumed in the fluid state, as distinguished from milk used for butter, cheese, condensed milk, and other products. It is estimated that in 1917 more than 16 billion quarts of market milk were consumed in the United States, which at 10 cents a quart would have been worth more than $1\frac{2}{3}$ billion dollars. Of course much of this milk was used on farms and in small towns, but probably not less than one-third was used in the larger cities. The greater part of the city milk was handled by so-called "middlemen" in city milk plants. These milk plants represented an investment of about 100 million dollars in buildings and machinery. The cost of land and delivery equipment would bring the total to considerably more.

Such an important business entails a great responsibility. Infants, children, and invalids, as well as healthy adults, depend to a great extent upon market milk. The supply must be brought sometimes from a distance of 300 or 400 miles, pasteurized, bottled, and delivered to the consumer generally each morning before breakfast. Furthermore, the milk must be handled under rigid sanitary conditions. For this business the modern city milk plant has been developed. These plants are constantly being remodeled, and new ones are being built to meet the latest advances in sanitation.

The purpose of this bulletin is to furnish specific information on the construction and arrangement of modern milk plants as an aid to those who wish to build new plants or remodel old ones. The information presented is based upon data obtained from surveys made of many of the principal plants in the larger cities of the United States.

PRIMARY CONSIDERATIONS IN ESTABLISHING A PLANT.

While starting a milk plant which insures a safe and adequate milk supply for a community is a laudable enterprise, it must be remembered that such ventures are not always successful. Many milk plants have failed, not because of faulty management or changed conditions, but because the milk plant should not have been established in the first place. Before the prospective operator engages in the milk business the following questions should be answered to his satisfaction.

1. Is the person who is to manage the plant familiar with the milk business? Unless a capable manager can be obtained the chances of success will be greatly lessened, as the success of a milk business depends primarily upon the manager. Besides being a good business man, the manager must be acquainted with the details of handling milk and of milk-plant operation. A man may have the proper character, personality, and business ability to manage some other kind of business and yet make a failure of the management of a milk plant, because he lacks the technical knowledge required.

2. Is there capital enough available to equip and operate a modern sanitary plant until it reaches a paying basis?

3. Is there a sufficient supply of milk of proper quality available or can enough be made available to operate the plant successfully?

4. Is there a steady demand for milk in the locality under consideration and is this demand being met by dealers already in the business?

5. What type of competition will be met with?

6. What is the attitude of the local health department? A capable health department can be of great help to a plant that is putting out a high-grade product.

7. What is the local labor situation?

8. Can the householders in the community be taught the value of milk as a food and be led to increase their demand? Are they able to pay a fair price for a high-grade product, and will they pay their bills promptly?

There are also minor considerations, but if the foregoing conditions are favorable the advisability of establishing a new plant in the vicinity will be greatly enhanced.

HINTS TO PROSPECTIVE BUILDERS.

The construction of a city milk plant requires careful study and planning. The building represents a large investment, as is shown in Table 8 under "Investment in milk plant." It is important, therefore, that the plans be carefully laid. The efficiency of the plant depends to a large degree upon the type of equipment used and the arrangement of the various rooms and machinery. It is possible for a well-arranged plant to effect great economies in labor, while a poorly planned plant may become a continual source of expense because of the extra labor required.

Any one contemplating building a new plant will do well to visit various up-to-date plants in different cities to get the latest ideas on construction, layout of rooms, and equipment. If it is impossible to visit other plants, plans and specifications sometimes can be obtained and ideas gained from them. By combining other dealers' ideas with his own the prospective builder can usually incorporate the best features of all in the new plant.

After selecting a site for the plant and determining about what is needed, the prospective builder should explain his general plan to a competent architect, who will draw up tentative sketches and plans which may then be studied in detail. Of course the type of machinery to be used must have been previously decided upon, since the general arrangement of the plant will depend a great deal on the type used.

It may be well to have several plans drawn, each adapted to a particular type of machinery. In case changes are found necessary they should be made in the plans before beginning the construction, as it is expensive to make alterations. It would be well also to have the plans reviewed by others experienced in the business and by health officials before the final plans are drawn.

After the plans and specifications of the building have been decided upon, bids should be obtained from several contractors in order to get the work done as reasonably as possible.

For a plant of small capacity much less detail is necessary and the plans can be completed frequently without the aid of an architect.

LOCATION OF PLANT.

The principal points to bear in mind in locating a milk plant are:

1. Ease of access from as many sides as possible.
2. Value of property.
3. Cost of getting the milk to the plant.
4. Proximity to distribution center.
5. Advertising possibilities.
6. Opportunity for retail counter cash trade.
7. Nearness to city water supply and electric power.
8. Avoidance of heavy traffic surroundings.
9. Good drainage.
10. Pure air and clean surroundings.

FIG. 1.—Exterior of a modern city milk plant.

Ease of access to the plant is very important. It is difficult to arrange a plant economically and conveniently unless it can be approached from at least two sides. A plant on a corner lot with an alley in the rear is desirable, but is seldom obtained in the down-town section of a city without great expense.

The high valuation of down-town property in many cities would be prohibitive for the location of a milk plant. In small cities, however, the extra advertising value and the cash trade gained by having the plant in the down-town section would often warrant such a location.

The cost of getting milk to the plant is an important consideration. If the bulk of the milk is received by railroad it may be advantageous to locate the plant near the railroad station, but if the milk is handled largely by truck, the vicinity where most of the milk comes into the city would be a convenient location. In case a large proportion of the milk is to be handled as bulk goods or wholesale deliveries, the wholesale section would have the advantage. If branch plants are to be established it may be well to locate the main plant where it can most easily receive the milk from the railroads. It is much less expensive to transfer bulk goods by truck than bottled goods, so that many dealers find it advantageous to have a main plant where most of the milk is received and to have branch plants near centers of distribution. Usually most of the trade of the branch plants is retail, while the down-town plant handles the greater portion of the wholesale trade. One plant having two branch plants had routes as follows:

	Wholesale routes.	Retail routes.
Main plant	12	39
Branch No. 1	4	26
Branch No. 2	3	28

By locating the plant near the center of distribution, delivery costs may be considerably lessened and in some cases two delivery trips may be made during the day.

Some dealers plan to establish the main plant in or near the section of the city where considerable development is anticipated. In this way they endeavor to obtain the trade of people moving into that section and the plant itself acts as an advertisement.

To serve as an advertising medium the plant must be situated where there is considerable travel, as in a retail shopping district, or at a street-car transfer point. The value of this form of advertising depends upon local conditions. In a small city it may be of considerable importance. The retail counter cash trade is usually of small importance in a large city, but in a small or medium-sized town this trade is often well worth considering. A plant on a much-traveled highway should draw this trade.

In few cities is there difficulty in getting an adequate supply of water and electricity, but, nevertheless, it is well to consider these items. Congestion of traffic is of small consequence in a small town, but in a large city it may assume considerable importance.

Good drainage for the plant and clean surroundings are essential for an up-to-date plant. Some plants are opposite parks and the air is very free from dust, while at plants in a thickly settled part of the city it is often necessary to filter the air that comes into the building.

In general, there are three locations in cities that may be selected for a milk plant: (1) In the wholesale district near the railroad,

(2) in the down-town retail section of the city, and (3) in the residential section. Heretofore it has been the general custom to locate the plant in the wholesale district near good railroad facilities. The tendency in recent years, however, has been to build it near the center of distribution rather than near the railroad terminal.

The advantages of having a milk plant in the wholesale district are:

Railroad facilities make it more convenient for receiving the milk.
It is a considerable distance from the residence districts, and there are less likely to be complaints of noise, smoke, etc.

The disadvantages of locating a plant in the wholesale district are:

It is away from the center of distribution.
There are no advertising benefits.
The district usually is rather insanitary and the air is filled with dust.
Property is often expensive.
Few retail counter sales are made at the plant.

The chief advantages of being in the retail district are:

Advertising benefits.
Retail counter sales, which are valuable not only for the actual sales made but for the new trade obtained thereby.

The principal disadvantages in the retail district are:

Property is expensive.
Less convenient for receiving milk.
May not be convenient for distribution.
More street traffic.

The advantages of a plant in the residential district are:

It is nearer the center of distribution and property is less expensive.
Retail counter sales are made and new customers obtained at the plant.
Pure air.
Less congestion of traffic and more quiet surroundings.

The disadvantages in the residential district are:

Poor railroad facilities.
Less advertising benefit.
Possible restrictions in regard to operation.

CLASSES AND TYPES OF PLANTS.

Plants may be classified, according to the method of handling the milk in the plant, into the following 6 classes:

1. *Gravity, more than one story.*—In this class of plants the milk in cans is elevated above the first floor and dumped. It then flows by gravity through pasteurizing and other machinery without the use of a milk pump.

2. *Gravity and pump, more than one story.*—Milk is elevated in cans above the first floor and dumped. It flows by gravity through

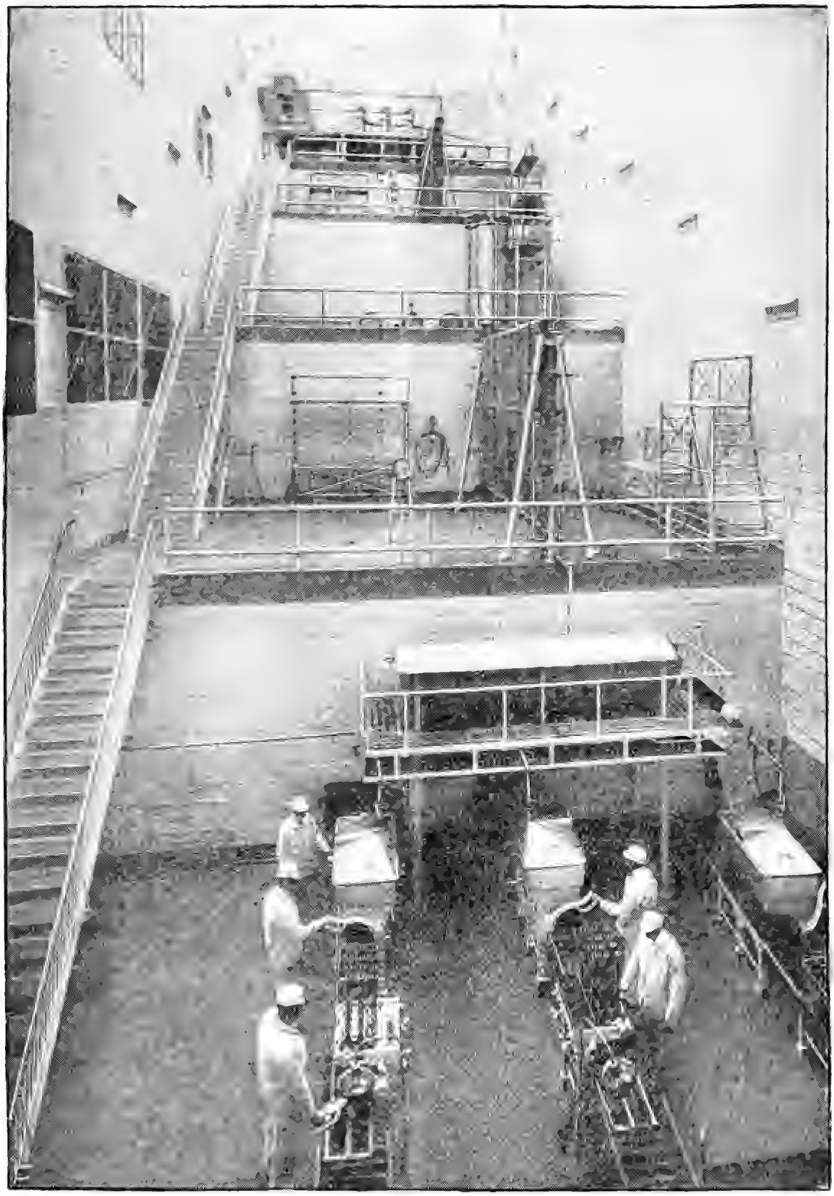

FIG. 2.—General view of equipment in gravity plant, class 1.

part of the machinery, but pumps are used also before it reaches the filler.

Classes 1 and 2 are rather uncommon, as most dealers seem to consider it uneconomical to elevate the milk in cans above the first floor.

From the ideal sanitary standpoint class 1 is to be preferred. Most dealers, however, do not consider it objectionable to pump the milk before pasteurization, provided the pump is of the right type and properly taken care of. The economy of dumping milk and leaving the cans on the ground floor is of considerable importance and much labor, time, and power may be saved by handling cans in that way rather than by elevating the full cans and, after dumping, sending them back on an elevator. Where there is not room enough on the ground floor for weighing, sampling, and grading it may be convenient to send the milk upstairs in cans. This system as a rule is more expensive, as is shown later in Table 2.

3. *Pump to higher level, then gravity.*—The milk is dumped into a tank on the first floor and pumped to a floor above, whence it flows through the various pieces of apparatus by gravity, without the further use of a milk pump.

Some of the most modern large plants, which vary in height from 2 or 3 stories upward, come under class 3. It is less objectionable to pump milk before pasteurization, when contamination can do less harm, than after. This type of plant also has the desirable feature of dumping and weighing the milk on the ground floor and is more economical in receiving milk than plants in classes 1 and 2.

4. *Pump to higher level, then gravity and pump.*—The milk is pumped from the first to a floor above. From that point it is handled by pumps, or partly by pumps and partly by gravity.

Many of the larger plants belong to class 4. This type has the economical advantages of the plants of class 3 and in addition permits greater economies in labor by the fact that the various pieces of apparatus are comparatively close together, and in some cases on fewer floors. In most of the plants of class 4 milk is pumped after pasteurization and the number of milk pumps and length of milk piping required are usually greater than in plants of the other classes. Many of the plants studied in this class were comparatively old.

5. *Gravity, one story.*—The milk is handled on one floor without milk pumps. Large quantities of milk can not be handled rapidly in such plants, and only the smaller plants come under this head. The plants of this class include a few small ones where the pasteurizer was raised on a platform and the milk dumped directly into it. Those handling between 501 and 1,000 gallons daily were raw-milk plants.

6. *Pump, one story.*—The milk is handled on one floor, one or more pumps being used. Class 6 includes some of the less up-to-date plants, which are usually frame buildings, built some time ago. The amount of milk piping required is comparatively large. Many of the smaller plants come under class 6; 48 out of a total of 55 handling less than 500 gallons each daily were in this class. A few of the

larger plants were included, but in most cases they were old and poorly arranged. In one of the latter as much as 300 feet of milk piping was used. Considerable economy of labor is often possible in plants of this type, however, as the one-floor system usually requires fewer men.

It is evident that plants in class 2 have few advantages over those in classes 3 and 4. They have the disadvantages mentioned in regard to time and labor of getting the milk upstairs, and pumps are used after pasteurization, which is not the case in classes 1 and 3, in which milk flows by gravity from the pasteurizer through the remainder of the equipment. One advantage they may have over the plants of class 3 is that less milk piping is required, for there is no piping from the ground floor to the receiving room upstairs.

A total of 174 plants of the principal dealers in the larger cities of the United States falls into the following classes:

Class.	Plants.	Class.	Plants.
1	2	5	10
2	5	6	83
3	17		
4	57	Total	174

Of the 83 plants in class 6, 48 each handled daily 50 gallons or less, and of the 57 plants in class 4, 29 handled 3,000 gallons or more each.

CONSTRUCTION OF PLANT.

SIZE OF BUILDING AND NUMBER OF STORIES.

In planning a milk plant, provision should be made for a building large enough to accommodate a reasonable expansion of the business. If possible the building should be so laid out that by the addition of more units of machinery the capacity of the plant can be increased from time to time without interfering with the convenient arrangement of the apparatus. Sometimes provision is made for adding another story.

A study of 105 representative milk plants showed that most of those handling less than 1,000 gallons daily have 1 story, while those handling from 1,000 to 5,000 gallons have 2 stories. Plants handling more than 5,000 gallons varied from 2 to 5 stories.

TYPE OF BUILDING.

The type of building selected depends upon local conditions and the type of machinery to be used. The more recently built plants are usually from 2 to 3 stories. There are but few advantages in a higher building, as labor requirements increase with the height. A gravity system for handling milk can be arranged as well in a plant of $2\frac{1}{2}$ stories as in a higher one. By either elevating or pumping the milk to a tank 2 or $2\frac{1}{2}$ stories high, gravity will do the work; that is, the milk will flow through the clarifier and the pasteurizer into the bottle-filling machinery without the use of a pump.

The principal advantage of building a higher plant is the smaller ground area needed when the plant is in a thickly settled part of the city; however, the tendency to build farther away from the downtown section is increasing, so that this consideration becomes of minor importance. The appearance of the building from the street is important, as it serves as an advertisement.

While the size of the plant as well as the number of stories depends on the quantity of milk to be handled, it should be so planned that one man can remain on one floor and not have to go from one floor to another in doing his work. Much time may be wasted if the men have to go upstairs and downstairs in their daily duties.

The ceiling of the plant should be at least 12 feet high. When the pasteurizing equipment is on the balcony, midway between the ground floor and the second floor, the handling room and the bottling room should be two full stories.

MATERIALS OF CONSTRUCTION.

The materials used for the construction of the plant depend a great deal on local conditions. The most satisfactory materials that may be used are reinforced concrete, hollow tile with cement finish, or selected brick. Cement blocks are also used to a limited extent. When concrete is used, the inside walls should be finished with a smooth surface and protected with paint that will stand hot water and steam.

At present the proportion of brick plants and wooden plants is large, but concrete is becoming very popular in many localities and is probably the most suitable for a milk plant. It is practically fireproof, very sanitary, weather resistant, and durable. Hollow tile with stucco finish is also much used for milk plants. With that type of construction the inside walls must be finished with cement or similar material. In certain localities cement blocks are used. This form of construction is usually found in the smaller plants and is very satisfactory, provided the material is not too expensive. The wood-frame buildings in nearly all cases are old ones. Many plants are now built of selected brick with cement finish on the inside, which is a very satisfactory type of construction.

INSIDE WALLS AND CEILINGS.

For the inside walls select a material that will provide a smooth, easily cleaned surface that is durable and waterproof. Concrete or cement is very commonly used and is quite satisfactory. This material can be finished with a smooth surface which is sanitary and can be easily washed with the hose. Walls should be coated with a paint as nearly waterproof and steamproof as possible. When wooden walls or partitions are used, the concrete of the floor should extend about 2 feet up the wall, as that part of the wall is exposed to water a large part of the time.

For inside walls of rooms where milk is handled, enamel brick, tile, enamel cement, or cement plaster is satisfactory. Tile or enamel brick is preferable but rather expensive. The different materials used in 20 plants which had special material for these rooms were as follows: Enamel brick, 12 plants; tile, 4 plants; cement plaster, 1 plant; enamel cement, 3 plants.

All the foregoing materials have a smooth surface and are easily kept clean. They give the room a sanitary appearance and are good reflectors of light. Enamel brick is less expensive than tile and is much used for the walls of milk-handling rooms.

Ceilings are usually constructed of materials similar to those used on the inside walls. The following were found in various plants: Wood, concrete, cement plaster, plaster on lath, and galvanized metal. As in the case of the inside walls, the ceiling should be smooth, durable, easily cleaned, and as nearly waterproof and steamproof as possible.

FLOORS.

Several large plants had wooden floors, but wood is a very poor material for floors where milk is handled. Wood is not durable and the milk soaks into it, causing bad odors and insanitary conditions. If a wooden floor is very tight it may be satisfactory for a short time if it is cleaned often, but its period of usefulness is short. Some form of concrete with a waterproof finish is the most desirable material. Frequently a hardener of steel filings mixed with the cement is used to form the finish, which makes the floor wear better. Sometimes, where an old building is used for a milk plant, a concrete floor may be laid over wood, if the underpinning is strong enough. If properly laid, a concrete floor is smooth and can be easily cleaned with hot water from a hose. Milk does not soak into concrete floors as it does into those of brick or wood. Concrete floors should have a good foundation with at least $3\frac{1}{2}$ inches of concrete below the top surface. Asphalt is sometimes used, but it is not very satisfactory because heat tends to soften it.

A tile floor in the bottle-filling room is desirable. Although more expensive when properly laid, it makes a good appearance, is durable, easily cleaned, and very sanitary.

Iron plates embedded in the cement protect the floor in rooms where cans and trucks are constantly being handled. An unprotected concrete floor wears out quickly if cans are continually rolled over it.

Floors in the milk-handling or washing rooms should have a slope of about one-fourth inch per foot toward the floor drains. Drains should be located when the floor is laid to insure a correct slope of floor and should be trapped and connected with the sewer. They should be from 6 to 8 inches wide and have perforated, removable covers. Great care should be taken in laying the floor to avoid making hollows in which water may collect. Before installing the plumbing it is advisable to be sure that it conforms to local plumbing regulations.

THE COLD-STORAGE ROOM.

The milk-storage or refrigerator room must be well insulated to keep the milk always at low temperature. The most common insulating materials are cork board, mineral wool, vegetable fiber, sawdust, and shavings, which are used as fillers in walls of wood, cement, or masonry. Cement should be put over the insulating material for the inside walls and ceilings to protect that material from moisture. The floors of the refrigerator should be of concrete laid solidly on the insulating material. The most satisfactory construction is about 4 inches of cork-board insulation with cement on the inside and outside.[1] Good drainage to a drain pipe, carefully trapped to prevent warm air from entering the room, is very important.

ARRANGEMENT OF PLANT.

HANDLING THE MILK AT ENTRANCE.

In the arrangement of rooms and machinery, economy of operation as well as sanitation must be considered. In the layout of the plant, provision should be made for the convenient and rapid loading and unloading of wagons. This applies to the delivery wagons and also to the trucks which bring the milk to the plant.

Some plants are so arranged that it is necessary for the trucks to be unloaded inside the building. Such a system is not conducive to rapid unloading. When the trucks drive inside the building there is a smaller space to turn in, and greater danger of contamination from dirt and dust of the street coming in through the open door of the receiving room. The use of a platform on the outside of the plant at the receiving room allows the milk to be handled much more readily. The platform need be only a few feet wide, but there should be ample space for two or more trucks to drive up to the platform at one time.

Upon the arrival of the trucks the milk is unloaded at once and sent to the receiving room, where it is dumped immediately. There is no needless driving and backing, as is the case when the trucks unload in the interior of the plant. If the unloading platform is

[1] For detailed information as to construction of storage rooms, see U. S. Department of Agriculture Bulletin 98.

outside, the truck can be quickly unloaded and another driven up immediately and unloaded. Usually two or more trucks can be unloaded at one time, which is not the case if they are unloaded within the plant.

Some plants with platforms outside greatly expedite the unloading and dumping of the milk by the use of roller conveyers. The platform should be covered to protect the workmen from the weather. The cans as they are removed from the truck are placed on the conveyers, on which they are carried to the dump or weigh tank. The cans may then be rolled on more conveyers to the can washer and thence to the can racks or back to the trucks. If the milk is received in this way the receiving room can be kept cleaner and the work can be done much more economically than if the trucks are driven into the building.

The unloading platform should be as close as possible to the receiving room and should be level with the floor of the truck, so that the cans of milk may be readily rolled from the truck. By having the dump tank close to the receiving platform and also lowered to the level of the floor, milk may be handled rapidly and with few men. It is desirable, however, to have the receiving room well inclosed and far enough from the street to reduce to a minimum the chances of contamination of the milk from that source. At many plants the platform can be most advantageously placed at some distance from the receiving room, even though more time and men may be required to receive and dump the milk. At such plants, much time and labor can usually be saved by the use of conveyers.

The plant should be so arranged that there will be no confusion of the milk trucks with the delivery wagons. A convenient arrangement is to have the receiving platform on one side of the building and the loading platform for delivery wagons on the other side.

In Table 1 a comparison is made of a few plants to illustrate three methods of arrangement for receiving the milk.

TABLE 1.—*Economy of various arrangements of plants for receiving and dumping milk.*

Type of plant.	Number of plants.	Average number of cans received per plant.	Average number of men per plant.	Average time per plant.	Average hours of labor per plant.[1]	Average hours of labor per 100 cans.	Average time per 100 cans.	Average cans handled per hour.
Truck unloaded inside plant and milk either dumped at ground floor or sent upstairs on elevators (no platforms used)	3	207	3.3	*Hours.* 2.5	8.3	4.0	*Hours.* 1.2	82.6
Trucks unloaded at platform and milk sent to receiving room on conveyers	3	643	4	4	19.0	2.9	.8	121
Trucks unloaded at platform and milk dumped in tank near by	2	500	2.5	3.2	8.7	1.7	.65	154

[1] "Man hours."

When the trucks were unloaded inside of a building that has no platform, considerably more time and labor were required to handle 100 cans of milk. The system of using conveyers to send the milk from the platform to the receiving room required more men and time than when the milk was dumped direct without the use of conveyers. This is due to the fact that at the plants where no conveyers were used the dumping tank was quite close to the receiving platform and less handling was required. The dump tanks at these plants were also sunk in the floor, so that very little lifting of the cans was required. In the plants where the conveyers were used the receiving room was much better protected from contamination, being further from the receiving platform and better inclosed. If conveyers had not

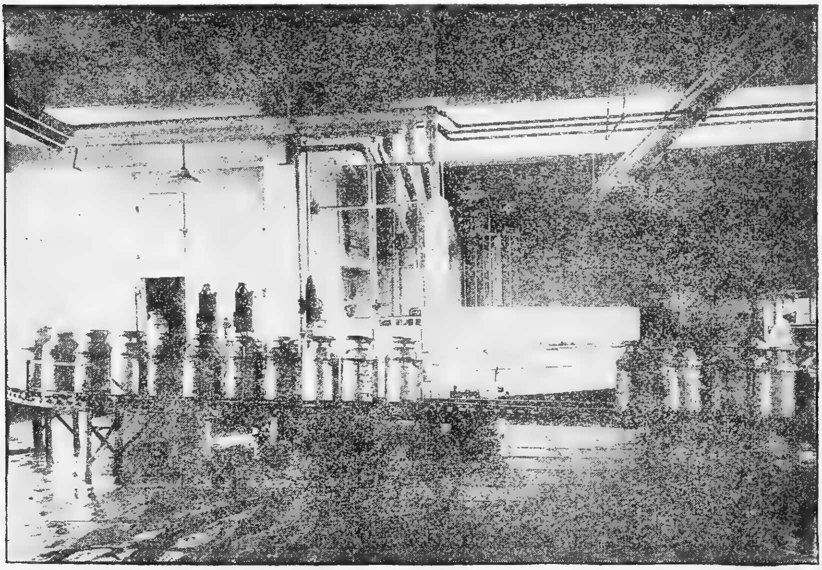

FIG. 3.—System of conveying cans and milk from the trucks to the dump tank, located at a considerable distance from the entrance to the receiving room.

been used at these plants more men would have been required. The necessity for a conveyer depends, of course, on the location of the dump tank with reference to the receiving platform.

MILK PUMPS COMPARED WITH ELEVATORS.

Very few plants elevated the milk to the top floor in the cans, the majority using pumps. Studies were made at 28 typical plants to determine the relative economy of the systems of (*A*) dumping the milk in tanks on the ground floor and then pumping from this tank to the receiving tank above, (*B*) raising the milk in cans to the top floor by means of power conveyers, and (*C*) raising the cans of milk by means of freight elevators. If conveyers are used trouble is sometimes experienced by a can being improperly placed on the apparatus and the milk spilled. A comparison of the economy of the three systems is shown in Table 2.

TABLE 2.—*Comparison of men and time required to receive and dump the milk and wash the cans at three different types of plants.*

Type of plant.	Number of plants.	Average cans of milk per plant.	Average time spent per plant.	Average number of men per plant.	Average hours of labor per plant.	Average hours of labor per 100 cans received.	Average time per 100 cans received.	Average cans received and dumped per hour.
			Hours.				*Hours.*	
A (pump)	18	1,034.7	4.9	4.3	26.2	2.5	0.47	212.6
B (conveyer)	6	845	4.9	5.7	30.8	3.6	.58	172.0
C (elevator)	4	825	8.1	5.8	58.4	7.1	.99	101.5

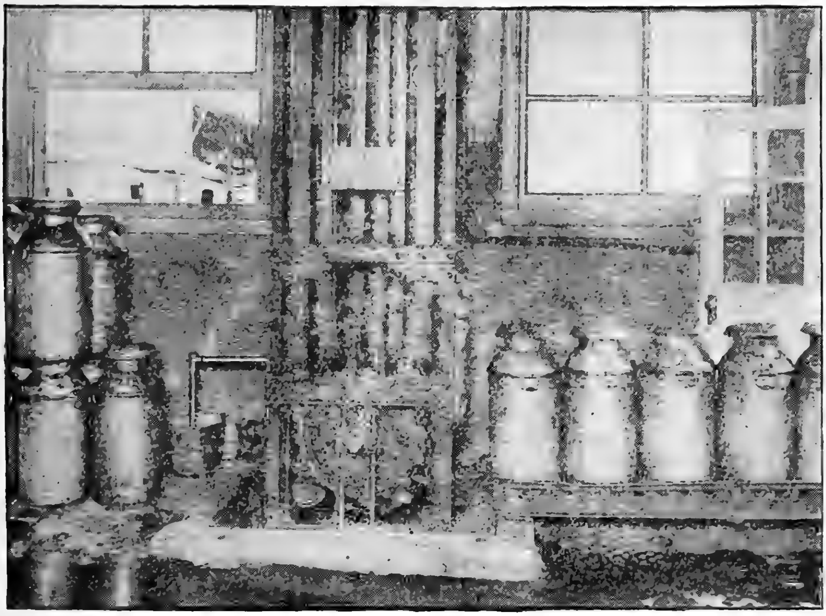

FIG. 4.—Gravity conveyers bringing cans of milk from trucks to power conveyer, which carries them to top floor where milk is dumped.

From the data in this table it is apparent that the system of pumping the milk from the ground floor rather than elevating it in cans is much more economical in the use of labor. At these plants the pumping system was more than twice as efficient as the elevator and much more efficient than the conveyer system. The conveyer system, however, is more economical in the use of labor than the elevator system and requires only about one-half as many man hours to handle 100 cans of milk. Of course, other factors enter into this problem, but these figures will illustrate the general tendency.

In some plants it may be necessary to have the receiving room on the top floor because of lack of space on the ground floor, but that is an arrangement to be avoided. Of course in plants where the number of cans handled is small, the element of time spent in receiving the milk is of less importance and conveyers or even elevators are often satisfactory.

LOADING DELIVERY WAGONS.

A study was made at several typical plants using different systems of loading delivery wagons, and the data obtained are shown in Table 3. The various systems studied were: (*A*) Wagons loaded in the interior of the building (milk trucked from storage room, no

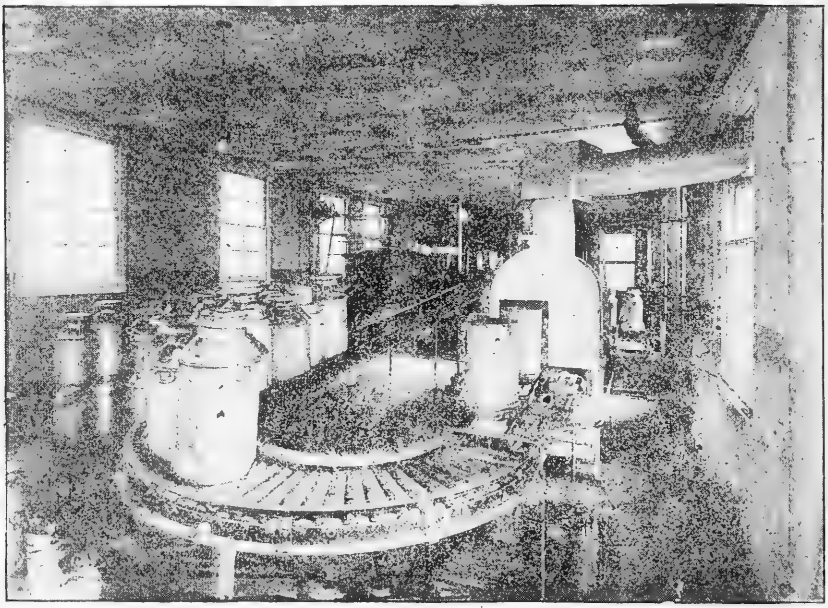

FIG. 5.—Dumping milk into weigh can from which it goes to glass-lined storage tank. Note gravity conveyers used to convey the empty cans from the dump tank to the can washer and then to carrier which conveys the clean cans down to the trucks. This system of receiving milk was much more economical as to time and labor required than the system of using freight elevators, but not so economical as the system of dumping the milk at the ground floor and pumping it and washing the cans downstairs.

platform); (*B*) wagons loaded from exterior platform (milk trucked from storage room); (*C*) wagons loaded from exterior platform (milk sent on conveyers from storage room to loading platform); (*D*) wagons loaded direct from storage room, one small door or chute being used; (E) wagons loaded direct from storage room, 2 doors or chutes being used; (*F*) same as *E*, except that 3 doors are used; (*G*) same as *E*, except that 4 or more doors are used.

The driver is included in all cases under "Average number men per plant." From the column "Average hours of labor per wagon" in Table 3 it will be seen that the time is greatest when milk is loaded inside the building, and that fewest hours of labor are required to handle milk loaded direct from storage room through two or more loading openings. In view of current labor costs this is a highly important point to consider in deciding on the arrangement of a milk plant. The cost of construction is an expense to be met only once, whereas the expense of labor is continuous.

TABLE 3.—*Comparison of time and men required to load delivery wagons at plants using various systems of loading.*

System of loading.	Number of plants.	Number of wagons loaded daily per plant.		Average number men per plant.	Average hours of labor per plant.	Average hours of labor per wagon.	Average time per plant.	Average time per wagon.	Average number wagons loaded per hour.
		Average.	Variation.						
							Minutes.	*Minutes.*	
A (inside building)	1	22	....	4	16	0.73	240	10.9	5.5
B (exterior platform trucks)	4	36.5	21–73	3.2	21.11	.58	314	8.6	7
C (exterior platform conveyers)	3	52.6	10–80	6	22.2	.42	180	3.4	17.7
D (direct from storage—1 door or chute)	1	16	....	3	7.5	.47	150	9.4	6.4
E (direct from storage—2 doors or chutes)	3	91	78–100	8	21.5	.23	160	1.75	34.3
F (direct from storage—3 doors or chutes)	6	75	50–130	5.3	14.5	.19	150	2	30
G (direct from storage—4 or more doors or chutes)	2	105.5	80–131	6.5	16.3	.15	160	1.4	42.9

It will be noted that there is a slightly less regular decrease in respect to "Average time per wagon," the size of the plant being a very important consideration in this problem. The sizes of the plants studied are indicated under "Average number wagons loaded per plant." System *G* would be practicable for only the larger-sized plants, while systems *E* and *F* would be impracticable for small plants. More men are usually required with systems *E*, *F*, and *G* than with systems *A*, *B*, and *D*.

It is usually desirable to load all the wagons within two or three hours if possible. The data in the table seem to indicate that when 75 to 100 or more wagons are to be loaded in this time either a conveyer system or a system of loading direct from the storage room through two or more doors or chutes is essential. While with these systems more men are required, the time per wagon loaded as well as the "Average hours of labor per wagon" loaded is considerably less than with the other methods, and the time element is very important where a considerable number of wagons are to be loaded.

These points illustrate the inefficiency of loading wagons within the plant and without having a platform. The milk must be brought from the storage room on hand trucks and each case of milk must be lifted from the trucks to the wagon. If the wagons are loaded from a platform or from chutes which are placed so high that they come even with the floor of the delivery wagon, very little lifting is required.

The figures in Table 3 also indicate that if a platform is used the system of trucking the milk from the storage room is much less economical as to time and labor than sending the milk out on conveyers. At a small plant loading only a few wagons the use of conveyers may not be practicable. One or two men besides the driver can handle the work, while in using a conveyer system more men may be necessary, although the time consumed would be less.

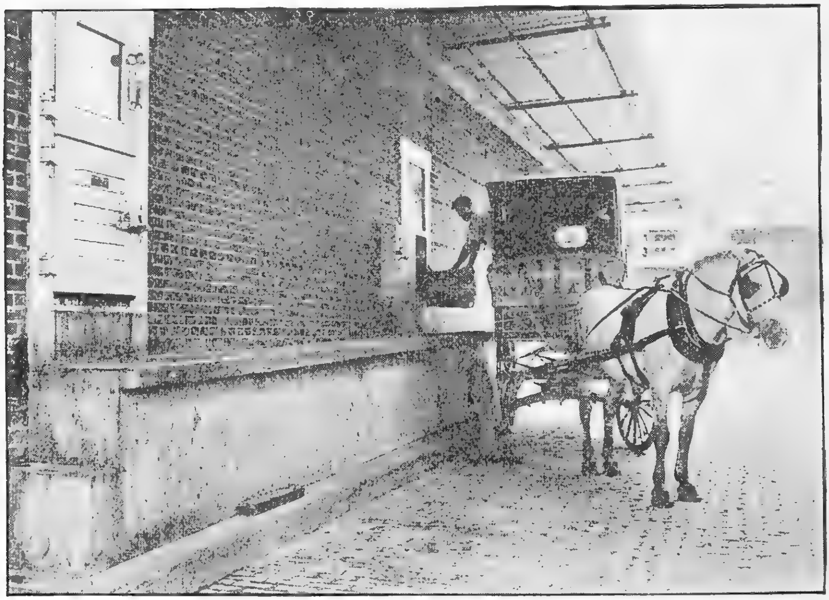

FIG. 6.—Loading delivery wagons at plant using system *E*. (The second chute was not in use at the time the photograph was taken.) An average of 34.3 wagons per hour were loaded at the three plants using this system. The average time required to load one wagon varied from 1.5 to 2.3 minutes.

The table also indicates that considerable time may be saved by using a conveyer rather than by loading the wagons direct from the storage room through one door or chute; though this means but little if only a few wagons are to be loaded. The hours of labor per wagon were not very different with the two systems, while the time per wagon was nearly three times as great with system *D* as with the platform-and-conveyer system.

At plants where two or more chutes from the refrigerator room are used, roller conveyers generally carry the milk from the rear of the room to the door, and usually one class of goods is put out at each door. For example, quarts of milk will be put out at door No. 1, pints at No. 2, and cream, etc., at door No. 3. As many wagons can be loaded at one time as there are doors. Thus the wagons are loaded in rapid succession and only slightly more than a minute (average) per wagon is required at some plants having three or more doors. When only one door is used more time is required per wagon. Where an exterior platform is used, whether the milk is conveyed from the storage room or trucked, usually two or more wagons may be loaded at the same time.

UNLOADING DELIVERY WAGONS.

Three systems of unloading the "returns" from the wagons returning from the routes are shown in Table 4.

TABLE 4.—*Time and men required to unload delivery wagons ("returns") at various plants using different systems.*

Type of plant.	Number of plants.	Average number of wagons per plant.	Average number of men per plant.	Average time per plant.	Average hours of labor per plant.	Average hours of labor per wagon.	Average time per wagon.	Wagons unloaded per hour.
				Minutes.			*Minutes.*	
A. Conveyer system (power or gravity)	8	88.4	3.7	177	11.2	0.13	2	30.0
B. Wagons unloaded on platform; then hand trucks.	3	57.6	2.6	240	11.5	.20	4.2	14.4
C. Wagons unloaded in interior of plant and hand trucks used	2	21	2	127	4.25	.20	6.1	9.9

It will be noted that for plants with a large number of wagons considerable time may be saved by using conveyers, as shown under system *A*, and that much time may be wasted by unloading the wagons within the plant. When a platform is used several wagons may be unloaded at one time, and when conveyers are used the driver simply throws his load on to the conveyer, and in this way the work is done at a rapid rate.

DIVISION OF ROOMS.

For economy of operation and sanitation, a division of rooms is essential in the modern milk plant. In many small plants the greater part of the work is done in one room, but in the larger and more modern plants a special room is provided for each operation. Each room should be laid out and constructed for the particular purpose for which it is designed.

In the receiving room the milk is inspected, sampled, and weighed. This room contains the weigh tank, scales, and milk-sampling outfit, and should be screened and separate from the other parts of the plant. After the cans are dumped they are drained, washed, sterilized, and returned. The can-washing apparatus should be located either in the receiving room or in a room adjoining it.

Handling room.—From the receiving room the milk goes to the pasteurizing rooms, where it is pasteurized and cooled before going to the bottling room. The latter room contains the fillers and cappers and should be well lighted, ventilated, and entirely sanitary. This is the room that attracts the attention of visitors. The bottles are inspected there for the last time and plenty of light is essential. In some plants this room is separate, while in others the pasteurizing and bottling are done in the same room. Usually the pasteurizing vats are upon a half or mezzanine floor. It is important to have this milk-handling room separate from other rooms in the plant.

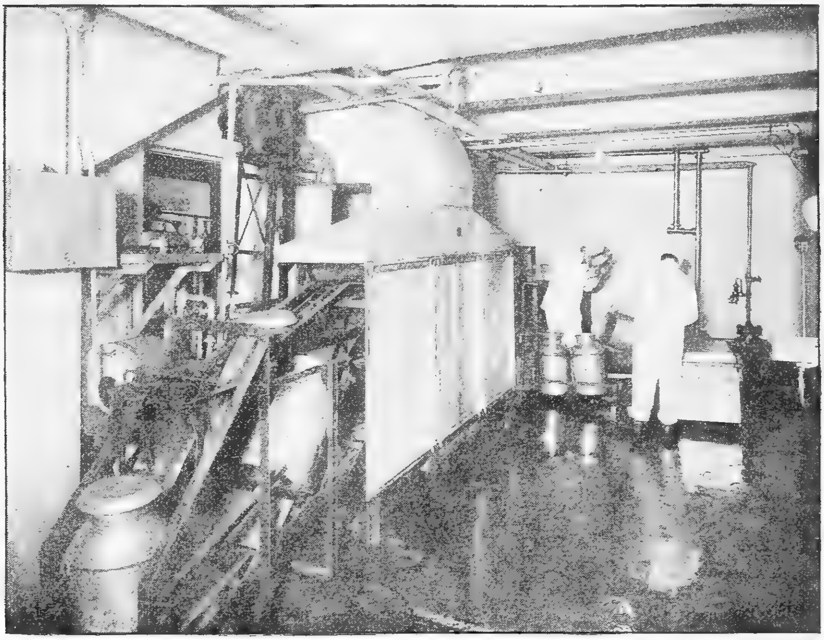

FIG. 7.—Receiving room with can washer.

Bottle-washing room.—This room should be separate so that no steam or foul air can pass into the rooms where milk is handled.

Clean-bottle storage room.—Between the bottle-washing room and the filling room many plants have a clean-bottle storage room where bottles are stored after being washed. This room must be cool and kept strictly clean, so that the bottles can cool and be kept free from dust or dirt. To obtain the best results, the air in the bottle-storage room is washed and artificially cooled.

Milk-storage room.—A well-insulated cold-storage room is necessary to keep the milk cold after it is put into bottles. The construction of cold-storage rooms is discussed on pages 12 and 24.

Salesroom.—The salesroom at the front of the building should be attractive in appearance and should contain a counter, a refrigerator, and perhaps a few chairs and tables for customers.

Drivers' room.—A room connected with the office should be provided in which drivers can score their books on returning from the routes. Bath and toilet facilities also should be provided for the drivers and men.

Laboratory.—A laboratory for the bacteriological and chemical examination of milk is essential for all plants. Small plants need only a small laboratory, while large ones require a complete laboratory with a full supply of chemical and bacteriological equipment.

By-products room.—Space should be provided for handling by-products. Small plants require space for making only small quantities of butter, cottage cheese, and buttermilk, which sometimes may

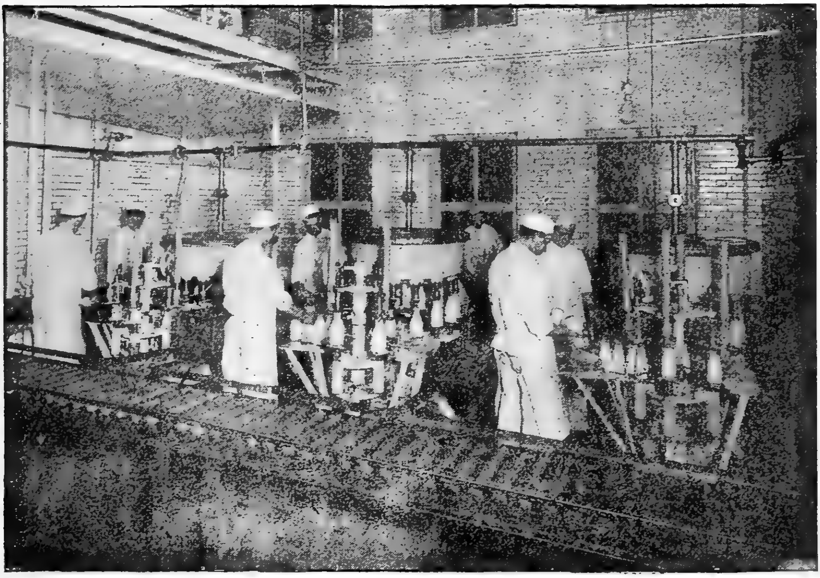

FIG. 8.—Filling and capping department. The bottles, after being filled and put in the cases, are sent on gravity conveyers to the milk-storage room.

be done in the milk-handling room. In medium-sized or large plants, however, one or more separate rooms are required for the by-products department.

SIZE OF ROOMS.

Each room in the plant should be large enough to avoid crowding the machinery or workmen, but at the same time there should be no unused space, for that causes extra labor in getting from one piece of apparatus to another.

There is a wide variation in the size of the various rooms in milk plants, as well as in floor area per 100 gallons of bottled milk handled daily. These variations are due in a large measure to the lack of standardization of milk plants and to the fact that many have been constructed without consideration of important factors bearing on the size of rooms.

Measurements from 5 modern, well-arranged plants that were built after careful study as to size of rooms are shown in Table 5. These plants were built in recent years and are giving satisfaction in regard to arrangement of rooms and machinery. The figures given illustrate the size of rooms that give satisfaction in modern plants.

It is important that the receiving room be of ample size. A small receiving room soon becomes crowded and "cluttered up" and is difficult to keep clean and attractive. There should be room enough to hold conveniently one or more truck loads of milk in cans and to

FIG. 9.—Bottle-washing room. Note use of gravity conveyers.

have plenty of room to handle the milk without crowding. It often happens that several loads of milk may arrive within a short space

TABLE 5.—*Floor space in various rooms of 5 well-arranged plants of various sizes.*

Quantity of bottled milk handled daily.	Receiving room.	Bottle-washing room.	Pasteurizing room.	Bottling room.	Total area for receiving, washing, pasteurizing, and bottling rooms.	Milk-storage room.	Clean-bottle storage room.
Gallons.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
1,000	400	600	500	300	1,800	450	400
1,500	....	700	550	375	1,625	550	....
3,000	900	1,050	1,300	1,200	4,450	1,200	750
4,000	460	1,886	540	700	3,586	1,426	540
6,000	1,200	1,908	720	720	4,548	1,110	720

of time and unless there are storage tanks it will have to remain in the cans in the receiving room until it can be dumped.

The size of the bottle-washing room depends somewhat on how the bottles are handled as they come from the delivery wagons. In case they have to be stacked in the wash room before being washed, a larger room will be required than if they pass directly from the delivery wagons to the washing machine and then on to the clean-bottle storeroom or the filling room. In case they do not have to be stacked, about all the space necessary is that required for the bottle-washing machine and ample room for the workmen to get around the machine. If the milk cans are washed in this room, additional space will be required.

FIG. 10.—Milk-storage room using direct system of cooling with cooling coils overhead. Note iron plates in floor.

The clean-bottle storage room should be large enough to accommodate conveniently at least all the bottles handled in one day. If it is desired to store more than a day's supply of bottles at one time, the room necessarily would have to be larger.

The pasteurizing room should be sufficiently large to contain the milk vats, clarifier, and pasteurizing equipment and still leave plenty of room for the men to work and to get around the machines for the daily cleaning. At some plants proper cleaning is often neglected because the men do not have space enough in which to work.

The bottle-filling room may be smaller than the other rooms, because usually the bottles pass continuously through it. When there is no clean-bottle storage room, however, the bottle-filling room will have to be big enough to store the clean bottles. It should also be large enough to allow plenty of room for the men to get around the filling machines for operating and cleaning.

The milk-storage room must be of sufficient size to hold all the milk that is to be handled, with space to spare for an emergency. Space should be allowed for a passageway between the tiers of various kinds of goods, such as pints and quarts of milk and jars of cream. Too large a room, however, is wasteful and requires additional refrigeration. The ceiling need not be more than 8 or 10 feet high after allowing for brine tank or pipes. A room 15 by 16 feet provides a space of 240 square feet. If cases of quarts are piled 6 high and pints 7 high, the space would provide for about 2,000 gallons of bottled milk in cases. Allowing space for the men to work and for emergencies, a room about 18 by 20 feet should be provided for 2,000 gallons of milk in bottles. A room 12 by 15 feet would provide space for about 1,000 gallons of bottled milk. In order to economize on refrigeration and insulating material the room should be as nearly square as possible. The proportion of milk that has to be held over in storage is one of the causes of the variation in size of storage rooms, as some plants send milk out on delivery wagons immediately after bottling without going to the storage room. When large quantities of milk are stored in cans more space is required, as cans of milk can not be packed so closely or so high as milk in cases of bottles.

The size of the by-products room depends upon the type of business conducted, but ample space must be provided for the churn, cheese vats, and similar equipment, with plenty of room for the men to work.

ARRANGEMENT OF ROOMS.

The rooms in the plant should be arranged so as to necessitate a minimum expenditure for machinery and labor; they should be so laid out that the work can be carried on with the fewest possible steps. It is desirable that the bottle-washing room, for example, be handy to both the boiler room and bottle-filling room. In this way little steam is lost in transferring it from the boiler to the washing room and the washed bottles are readily transferred to the filling room.

The bottle-washing room should also be so situated that the returned bottles may pass directly from the receiving platform to the washing machines. In some plants the bottle-washing room is directly under or over the filling room, which may be convenient where there are facilities for elevating or lowering the bottles. If there is space enough, however, it is generally more convenient to have the washroom and the bottle-filling room on the first floor.

The location of the cold-storage room depends on various considerations, but if possible it should be situated so that the milk can go directly into it from the bottling room. It should also be accessible to the delivery wagons, so that they can be easily and quickly loaded. To save refrigeration only a minimum wall surface of the refrigerator should be exposed to outside air or sun. Usually windows are unnecessary in the refrigerator. If there are windows they should have three or more thicknesses of glass with spaces between, and the glass should be covered with white paint to exclude the direct rays of the sun. When not needed all artificial lights should be extinguished, as they increase the room temperature.

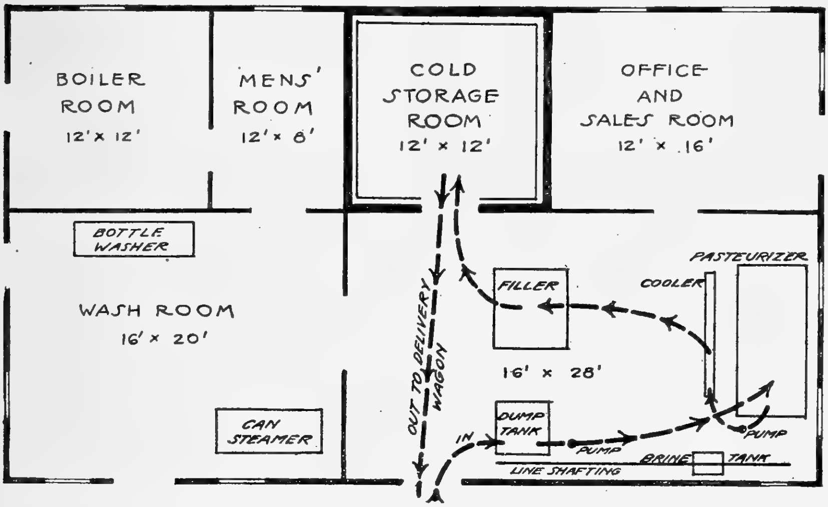

FIG. 11.—Floor plan for a 1-story plant of about 500 gallons' daily capacity, showing course of milk through plant.

The doors of the refrigerator room should fit tightly, swing outward, and be adapted to quick handling. Doors swinging inward reduce the storage space considerably. A vestibule to the refrigerator room, while taking up some extra space, prevents a considerable loss of refrigeration.

ARRANGEMENT OF EQUIPMENT AND MACHINERY.

Equipment should be arranged to permit easy cleaning. In some plants tanks are so placed that the man who cleans them has to squeeze in between the top of the tanks and the ceiling in order to reach them. Much time is saved by convenient arrangement and the cleaner will be less liable to neglect the work.

Machinery should be placed so as to minimize labor requirements and to use space most economically. Another point to be considered in placing the machinery is the reduction to a minimum of conveyers, pumps, pipes, and fittings. This applies not only to milk piping but also to water and steam piping. Large quantities of piping and fittings are expensive, cause extra labor, and in the case of milk pipes may be insanitary. The course of the milk through the plant should be as direct as possible from the receiving tank, through the clarifier, pasteurizer, and bottling machines to the cold-storage room. Mechanical conveyers should be used whenever labor and time can be saved; otherwise the extra expense incident to their use is not warranted.

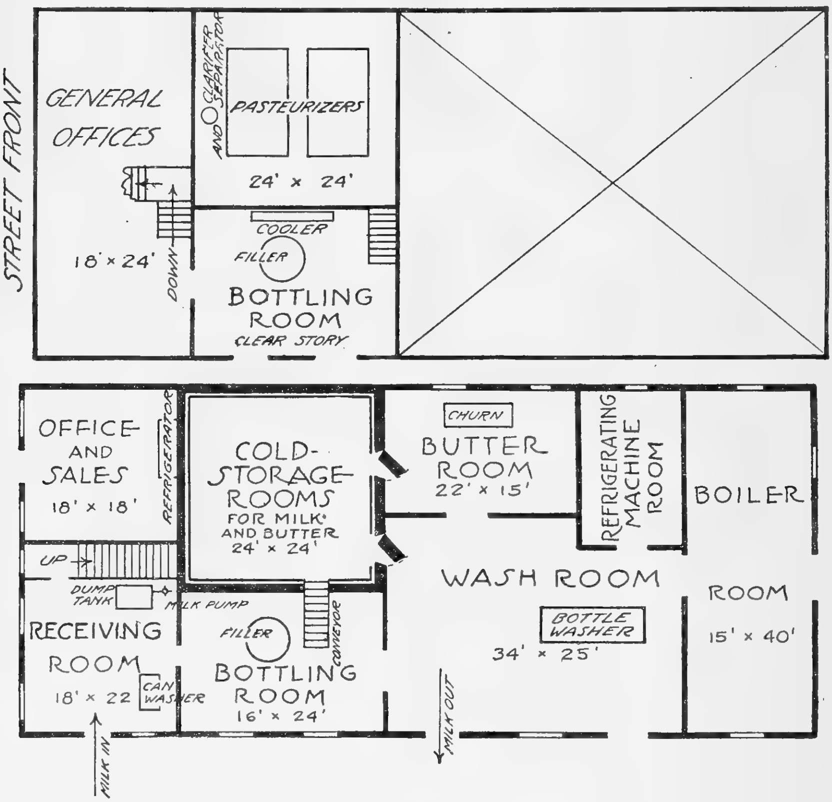

FIG. 12.—Floor plans for a 1½-story plant of from 1,500 to 2,000 gallons' daily capacity, where butter also is handled.

At 73 plants the number of milk pumps used varied from none to 4, and the milk piping used from none to 300 feet. A wide range occurred in plants in the same class, as well as in plants of the same size. For example, at 26 plants of class 4 the length of milk piping varied from 20 to 210 feet, and the number of milk pumps varied from 2 to 4, and at 20 plants handling from 2,001 to 5,000 gallons daily the length of the milk piping varied from 30 to 300 feet and the number of milk pumps from none to 4.

Great lengths of milk piping cause extra labor and expense and tend to increase the loss of milk both from milk sticking to the sides of the pipes and from leaks at joints. If piping must be used, it should be of simple and sanitary construction, with frequent unions to permit thorough cleaning and sterilizing after each use. It is important to have all turns in the pipes easily accessible and easily cleaned. Elbows and tees are to be avoided as much as possible, but when they are used, openings at the end will facilitate cleaning. A right-angle bend may be used if there is space, for in this fitting there are no recesses in which dirt can collect. When such joints are used the piping may be more easily kept clean.

The pumps as well as the pipes should be cleaned and sterilized each time after using. It is less objectionable to use milk pumps before pasteurizing than after, for milk pumped after pasteurization may be recontaminated if the pump is not clean, and the added agitation may injure the cream line. Pumps should be of sanitary construction and of sufficient capacity to do the work without being overtaxed.

EFFECT OF ARRANGEMENT OF PLANT ON LABOR REQUIREMENTS.

The number of employees required to carry on the various operations in the plant depends to a large degree on the layout and size of rooms, arrangement of machinery, and size and type of building. Table 6 shows the number of men employed at 157 plants of various sizes. They include only those in the plant and in the boiler and engine rooms. In plants where ice cream is handled the time of the men in the power plant was prorated according to the quantities handled, and where there was a separate butter department the men who put all their time in that department were not included. The figures given do not necessarily indicate the total number of men employed at one plant, but one man indicates a full day for one man, as, for example, when the average number of employees is given as one, it may indicate that one man spends one-half of his time and two others one-fourth of their time each in the plant.

TABLE 6.—*Number of men employed in city milk plants of various sizes (men inside the plant only).*

Capacity of plant.	Number of plants.	Quantity of milk handled daily.		Employees in plant.			Employees in plant per 100 gallons handled. Average.
		Total.	Average.	Total.	Average.	Variation.	
Gallons.		*Gallons.*	*Gallons.*				
Up to 100	4	250	63	4.3	1.1	1 to 1.3	1.7
101 to 250	19	3,285	173	32.5	1.7	1 to 3	1.0
251 to 500	31	12,435	401	86.5	2.8	1.5 to 6	.7
501 to 1,000	34	26,885	790	193.0	5.7	2 to 13	.7
1,001 to 1,500	16	20,750	1,297	114.5	7.2	2.5 to 17	.6
1,501 to 2,000	11	19,600	1,782	126.0	11.5	6 to 21	.6
2,001 to 3,000	13	34,450	2,650	190.0	14.6	8 to 27	.6
3,001 to 5,000	16	64,650	4,041	328.0	20.5	7 to 36	.5
5,001 to 10,000	9	66,700	7,411	294.0	32.7	9 to 49	.4
Over 10,000	4	69,000	17,250	343.0	85.8	49 to 100	.5
Total or average	157	317,975	2,025	1,711.8	10.9	1 to 100	.5

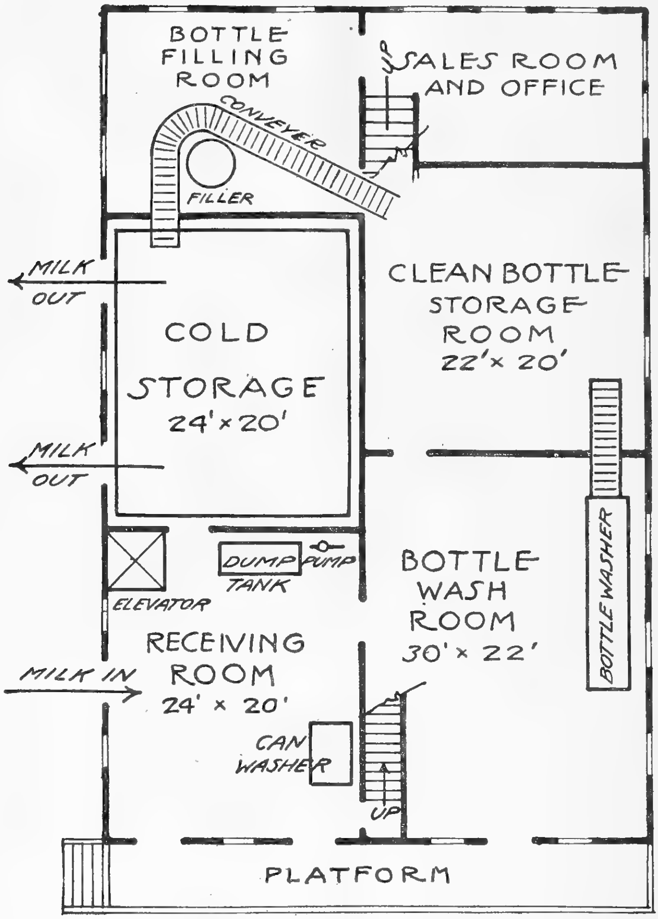

FIG. 13.—First-floor plan of a two-story plant of from 2,000 to 3,000 gallons' daily capacity.

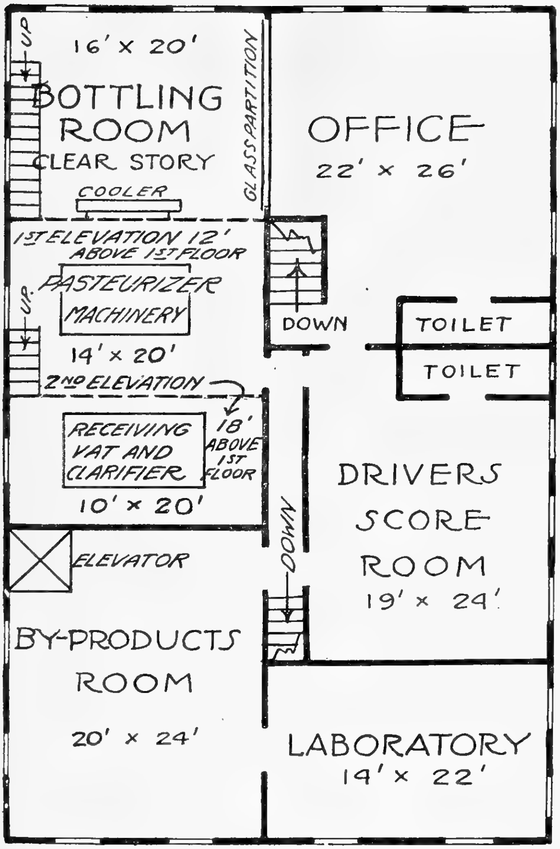

FIG. 13A.—Second-floor plan for a two-story plant of from 2,000 to 3,000 gallons' daily capacity.

NOTE.—Blue prints showing approved plans for milk plants of various sizes and arrangements may be obtained free on request, by those contemplating the erection of such plants, from the Dairy Division, U. S. Department of Agriculture, Washington, D. C.

The average number of men in each plant bears a very close relation to the quantity of milk handled. It will be noted, however, that there is a wide variation in the number of men employed at the various plants in each group. Some plants employ six times as many men as others of the same size. Although some other factors are involved, such as the relative quantities of bottled milk handled, these figures effectually illustrate the fact that some plants are not operated so efficiently as others, which is due, to a great extent, to the faulty layout and arrangement of rooms and machinery. Many plants could cut down their labor by a more economical layout of machinery and equipment, while others could reduce it by installing more labor-saving machinery. Some plants have too many floors or stories to be able to utilize labor efficiently. For example, it is often necessary to have a set of men with a foreman on each floor. It can be readily seen that a plant with four or five floors requires more men and can utilize labor less efficiently than a plant handling the same quantity of milk with only one or two floors, although the latter plant may have nearly as much floor space as the larger building. The gravity system of milk handling (which is now generally recognized as the most efficient) can be used as well in a plant of 2½ stories as in one of 4 or 5 stories. By having the pasteurizing equipment on a mezzanine floor, practically all the milk handling can be done in one room; the gravity system of handling can be used and the number of men can be reduced to a minimum.

SANITARY REQUIREMENTS.

WATER SUPPLY.

An abundant supply of water should be available at the plant at all times. Large quantities of water are required for pasteurizing and cooling, for boilers and refrigerating machinery, and also for washing purposes. The quantity required for washing bottles and cans and cleaning up milk apparatus is considerable, and, besides, there are the requirements necessary for keeping the floors and walls well washed. Table 7 gives the quantity of water used at several plants of various sizes.

TABLE 7.—*Quantity of water used at milk plants of various sizes.*

Capacity of plant (gallons).	Average quantity of milk handled daily.	Quantity of water used daily.		Quantity of water used daily per 100 gallons milk handled.	
		Average.	Variation.	Average.	Variation.
	Gallons.	*Gallons.*	*Gallons.*	*Gallons.*	*Gallons.*
Up to 1,000	500	4,800	(1)	960	(1)
1,001 to 2,000	1,566	14,255	11,000 to 18,300	909	520 to 1,220.
2,001 to 3,000	2,692	11,722	6,710 to 17,235	436	287 to 580.
3,001 to 5,000	3,500	17,735	3,070 to 32,400	509	77 to 1,080.
5,001 to 10,000	6,788	16,135	(1)	238	(1)
Over 10,000	15,999	112,007	102,000 to 122,015	700	611 to 850.

[1] Only 1 plant in group.

STEAM.

It is important that all milk-handling equipment be sterilized immediately after washing, and plenty of live steam must be available. A convenient arrangement is to have a valve connected with the city water and with the steam system. By the use of such connection either hot or cold water or steam is made available. (Hot water can be obtained by turning on both the water and steam valves.)

VENTILATION.

Good ventilation is essential in a milk plant in order to get rid of the bad air and moisture and to insure pure air. In many plants the ventilation is inadequate, often being obtained by means of windows and doors only. It is difficult to get good ventilation by this method. Even in a medium-sized plant exhaust fans should be used to take out the bad air and moisture. Many modern plants have an artificial system of ventilation by which air as pure as can be obtained is drawn through a filter or through a spray of water and then forced by fans through flues into the rooms. The openings from these flues or ducts into the rooms may be near the ceiling or near the floor, but usually they are about midway between. By heating or cooling the spray of water the temperature of the air in the rooms may be controlled to a certain extent.

In large plants the process of filtering air consists in forcing it through one or more thicknesses of cheesecloth, or cloth and absorbent cotton. The air is forced into the room through the filter under a small pressure, so that the used air has a tendency to pass outward through the openings near the ceiling provided for outgoing air. All air coming into the room must pass through the filter, which should be changed often. At some plants before the air is forced into the rooms it is cooled in summer by passing over brine coils and warmed in winter by passing over steam coils.

For a medium or small plant there should be some system of artificial ventilation. A flue system similar to that used in dairy barns is quite efficient and is not expensive. By simply installing outlet flues through which the air can pass out and allowing air to come in through the windows, fairly good ventilation can be obtained.

In many plants the cold-storage room is very poorly ventilated. It is, of course, impracticable to have open windows in this room; consequently if an artificial system of ventilation is not used the ventilation is poor and the best results are not obtained from the cooling coils. There is also a condensation of moisture on the ceiling and a constant dripping, which is very uncomfortable and insanitary.

In plants where artificial ventilation is impracticable considerable improvement can sometimes be made by using an ordinary electric fan, which will keep the air in circulation and produce better results from the cooling coils.

A considerable number of modern plants have an indirect method of cooling the cold-storage room which also serves as a ventilating system. The air is blown over bunkers or refrigerating coils in another room and then through flues into the cold room. The cold air drops as soon as it reaches the openings in this room and the warmer air passes out through other openings and is again drawn over the refrigerating coils, so that a constant circulation of clean, dry, cold air is maintained.

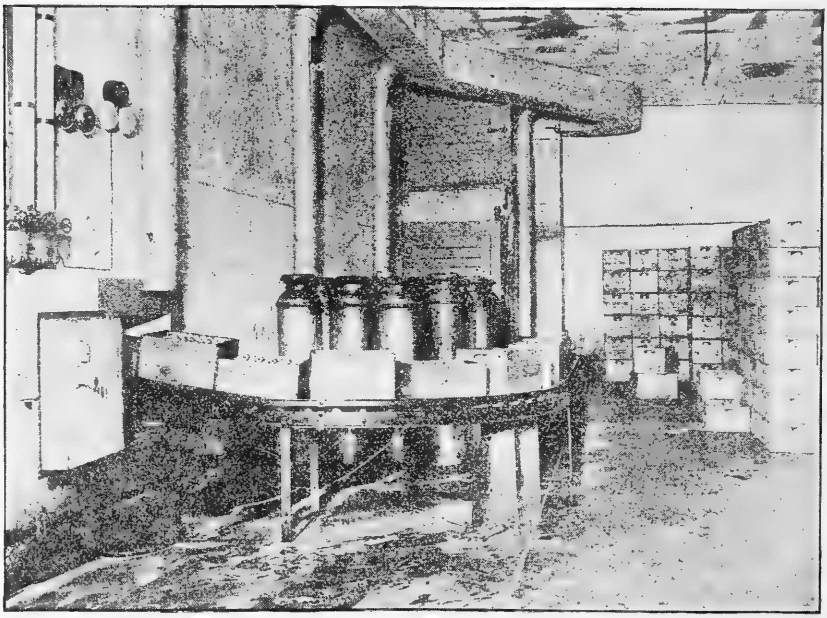

FIG. 14.—Milk-storage room with indirect system of cooling. Note flues through which the cold air is fanned into the room, also system of conveying the milk into the room from the bottling room.

MISCELLANEOUS REQUIREMENTS.

Screens should be attached to all windows and doors during the fly season. The screens should be outside and open outward. The receiving room especially should be well closed in and screened, and self-closing doors should be attached to the room as well as to others through which workmen pass continually. Electric fans will also aid in keeping flies away from the milk and equipment. Double doors at the entrance of the plant with fans blowing toward them will greatly aid in keeping the flies out.

It is important to have a special room for the drivers and other employees. In this room a locker for each man's working clothes is essential, and shower baths and toilet facilities should be provided in an adjoining room.

The milk plant frequently can operate a laundry to advantage, especially if the men's white working suits are washed by the plant. If cleaned at the milk plant's expense the men will be more likely to change them often.

Aside from the general toilet facilities it is advisable to have a washbowl, with soap and towels handy, in the milk-handling room. Employees in the handling room often get their hands dirty from setting up machinery, handling bottles, cases, etc., and it is essential to have a convenient place for them to wash their hands before handling sterilized bottles or engaging in other operations concerning milk.

Milk apparatus should be covered so as to expose the milk to air as little as possible. This caution refers especially to vats, coolers, and bottling machines.

Those dealers who have a business large enough to warrant the maintenance of a laboratory for the careful supervision of the quality of milk are in a much better position to safeguard the milk which goes out from their plants.

COST OF PLANT.

The amount of money that must be invested in a milk plant depends primarily upon the volume of business to be carried on. Whether it is desirable to erect an expensive building depends on local conditions. To give some idea of the cost, Table 8 has been compiled to show the investment in building at 84 representative milk plants of different sizes. In some cases if sufficient capital is not available it may be desirable to rent a building for a time rather than build a new plant, but if a new one is built it is advisable to erect a permanent, sanitary building of modern construction. While the first cost may be high, the permanent nature of the building will make the actual overhead expense for depreciation relatively small.

TABLE 8.—*Investment in buildings for milk plants of various sizes; stables or garages for delivery equipment not included.*[1]

Size of plant (gallons).	Number of plants.	Milk handled daily.		Investment in milk plant.		Investment per 100 gallons handled daily.	
		Total.	Average.	Total.	Average.	Average.	Variation.
		Gallons.	*Gallons.*				
100 or less	5	430	86	$9,000	$1,800	$2,093	$1,000 to $7,143
101 to 250	9	1,935	215	18,000	2,000	930	217 to 3,000
251 to 500	23	9,065	394	86,900	3,778	958	200 to 6,000
501 to 1,000	14	10,655	761	110,335	7,881	1,036	200 to 2,063
1,001 to 1,500	10	13,040	1,304	142,546	14,254	1,093	333 to 2,917
1,501 to 2,000	5	9,200	1,840	116,000	23,200	1,261	250 to 2,000
2,001 to 3,000	4	10,383	2,596	127,074	31,768	1,224	126 to 2,252
3,001 to 5,000	8	33,350	4,169	436,763	54,595	1,309	268 to 2,000
5,001 to 10,000	3	26,000	8,666	450,000	150,000	1,731	1,250 to 2,500
Over 10,000	3	39,000	13,000	534,775	178,258	1,371	1,233 to 1,500
Total or average	84	153,058	1,822	2,031,393	24,183	1,327	126 to 7,143

[1] These figures are based on conditions n 1916–17.

Great variations in investments in plants of the same group were noted. In the group handling from 251 to 500 gallons of milk daily this variation was from $600 to $10,000. The wide variation was largely due to the fact that some of the plants were old wooden buildings not at all suitable for the purpose, while others were modern buildings of permanent construction and in some cases much more expensive than was necessary.

It will be seen in Table 8 that while the average investment is directly proportional to the quantity of milk handled, the average investment per 100 gallons handled daily varies considerably. This investment is the highest for plants handling less than 100 gallons. Plants of that size usually have a relatively high overhead expense on account of the investment in buildings, except when cheap or temporary buildings are used.

Plants handling from 101 to 250 gallons daily had an average investment of only $200 higher than plants handling 100 gallons or less and also had the lowest investment per 100 gallons handled of all groups studied. Apparently this size of plant is economical so far as investment in building is concerned. As a general rule the investment per 100 gallons handled increases with the size of the plant up to 10,000 gallons. This is due to a large extent to the fact that the general tendency is for the larger-sized dealers to have more elaborate plants. Although more expensive they serve as an advertising medium. The plants handling more than 10,000 gallons were equally well appearing, but the large quantity handled brought down the investment per 100 gallons. Since these figures were obtained there has been a great increase in the cost of materials, labor, and supplies.

CONCLUSIONS.

1. Conditions should be thoroughly investigated and found to be favorable before attempting to establish a milk plant.

2. For large plants the assistance of a competent architect in making plans is required. Plans for a small plant can often be drawn without such aid.

3. Favorable location of the milk plant is important. In general there are three locations that may be selected for the plant: (1) In a wholesale district; (2) in a down-town retail section; (3) in a residential section. Each of these has its advantages and disadvantages.

4. Plants may be classified, according to the way the milk is handled, into 6 classes. Gravity plants are to be desired, but often the labor required to operate plants of two or more stories is greater than in 1-story plants.

5. Large plants are usually of two or three stories.

6. The milk plant should be modern in every way and should be of good appearance from an architectural point of view.

7. Up-to-date plants are usually constructed of bricks, concrete, or hollow tile, finished on the inside with smooth cement, and on the outside with stucco.

8. Inside walls should have a smooth finish. Tile or enamel brick are desirable for the bottling and pasteurizing rooms.

9. Concrete floors are desirable in all milk plants. Tile floors in the bottling rooms add to the appearance.

10. Floors must be well drained and have proper connection with the sewer.

11. Economical arrangement of the plant is important. There should be an outside loading and receiving platform. It is more economical of labor and time to dump the milk into a tank on the ground floor and then pump it rather than raise it by conveyers or elevators. To unload the milk truck on the inside of the building is an uneconomical arrangement.

12. Where a large number of delivery wagons are to be loaded, loading through 2 or more chutes direct from the storage room will save time. Wagons should be loaded from an exterior platform, and conveyors are more economical in the use of labor and time than hand trucks.

13. In unloading the delivery wagons a conveyer system often saves time and labor.

14. For convenience, economy, and sanitation the plant should be divided into the following separate rooms: Receiving room, pasteurizing or handling room, bottling room, wash room, by-products room, milk-storage room, salesroom, offices, laboratory, etc.

15. Each room should be of ample size to accommodate the equipment it contains, with sufficient space for the men to work and to clean the equipment, but there should be no waste space.

16. The rooms in the plant should be so arranged as to necessitate the minimum expenditure for machinery and labor, and so laid out that the work can be accomplished with the fewest possible steps. There should be a minimum of milk piping and pumps, for both economical and sanitary reasons.

17. Poorly arranged plants tend to increase the labor requirements.

18. The plant should be sanitary in every way; plenty of water and steam should always be available; good ventilation and light are essential.

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H. C. TAYLOR, Chief

Washington, D. C. ▼ April 30, 1920

COUNTIES

RENT CONTRACTS IN TYPICAL COUNTRIES OF THE WHEAT BELT.

By E. A. Boeger, *Agriculturist.*

CONTENTS.

SOURCES OF INFORMATION.

THE FACTS upon which this discussion is based were procured primarily for the purpose of acquainting the tenants in any of of the principal wheat-producing States with the methods of renting in vogue in other parts of the region. It was thought, also, that the information collected would be welcomed by both landlords and tenants as increasing their knowledge concerning the renting of farms in their own localities.

The material here presented was gathered in the spring of 1917, from tenants who were visited on their farms in the various localities chosen for the inquiry. Two considerations governed the selection of the counties to be visited, viz, the relative importance of the wheat crop and the per cent of tenancy. The desired combination of conditions seemed most likely to be found in Barton County, Kans.; Clay County, Nebr.; Spink County, S. Dak.; Barnes County, N. Dak.; and Renville County, Minn. (For the location of the counties visited, see fig. 1.) The number of records obtained in these counties, in the order named, was 80, 91, 79, 71, and 82, respectively.

DESCRIPTION OF AREAS.

When comparing ways of renting in any one county with those of another, it should be taken into account that though each of the counties in which investigations were made is situated in a typical wheat-producing area, the organization of the farms and the practices differ more or less on account of differences in geographical location.

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Barton County, Kans., is about the center of the great winter-wheat producing area of the Great Plains. Spink County, S. Dak., and Barnes County, N. Dak., also in the Great Plains, are located in the center of the principal spring-wheat producing area of the United States. In Barton County farms were between 300 and 400 acres in size, and in the more northern of the counties just mentioned they were somewhat larger. In each of these counties about half the farm land was in small grain. In Barton County nearly all the grain was wheat. In the three other counties about one-third was flax, barley, emmer or speltz, and rye, thus indicating greater diversity of small grain. On

FIG. 1.—Shaded areas indicate counties in which records were obtained.

the basis of hay and forage production, available pasture, and by-products, the counties have approximately equal carrying capacity for live stock. Rainfall is the most important factor influencing yields of wheat, which, broadly speaking, vary from 5 to 20 bushels per acre, the average being about 13 bushels.

The most distinguishing characteristics of farming in these counties are the high percentage of farming land in broadcast crops and the absence of clover and grasses in rotation. Although a small acreage on each farm frequently is devoted to alfalfa, this crop does not take the place of clover and grasses, which in general mixed farming are so important a feature in rotation with other crops.

Clay County, Nebr., and Renville County, Minn., represent typical farming along the border of the Corn Belt. Clay County is on the western edge of the Corn Belt in the winter-wheat zone, while Renville County is near the southern boundary in the spring-wheat zone. In each of these counties corn about ranks with wheat, and clover and grasses are of some importance in crop rotations. These character istics, together with the fact that the capacity of the farms to carry live stock is high, would tend to make agriculture in these counties of the general mixed farming type. The average yield per acre of wheat is from 2 to 3 bushels higher than in the counties first mentioned and the risk in farming is somewhat less, owing to the greater importance of live stock and to greater diversity of crops.

SYSTEMS OF RENTING FOUND.

Six distinct systems of renting were found in the localities visited. These systems are named after the share of the crops the landlord receives, or from what is paid for the use of the land. They are classified in Table I in the order of their relative importance. Under the first four, the landlord is given a share of the crops only, as one-third, two-fifths, one-half, or two-thirds. The fifth system gives the landlord a half share of both crops and stock, and the sixth is a cash rent system.

TABLE I.—*Comparative percentage of tenants who rent under each system of renting found in the different locations.*

Locality.	Landlord's share of crops.						
	One-third.	Two-fifths.	One-half.	Two-thirds.	One-half crops and stocks.	Renting for cash.	Total.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Kansas: Barton County	79	4	9	3	3	2	100
Nebraska: Clay County	75	20	3	0	0	2	100
South Dakota: Spink County	42	0	53	0	2½	2½	100
North Dakota: Barnes County	7	0	88	0	5	0	100
Minnesota: Renville County	61	7	15	0	2	15	100

ONE-THIRD SHARE.

Under this system, the landlord receives one-third of the grain, usually delivered from the thrashing machine but sometimes temporarily stored in bins on the farm. He furnishes land, dwelling, barn, and usually all other farm structures; fences, material for repairs and skilled help for making repairs when necessary; grass seed when sown; and usually pays the real estate and road tax. The tenant furnishes all labor, work stock, machinery and tools, grain seed, and pays for the twine and the expense of thrashing.

EXCEPTIONS.

In the southeastern part of Clay County, Nebr., if the landlord receives one-third of the crop the tenant sometimes pays all or a part of the real estate tax. On these farms the tenant usually owns all the farm fences and structures except the dwelling, barn, and wind mill, and must keep them in repair at his own expense. When such tenants move, they may remove their fences and structures or sell them to the incoming tenants. On these farms pasture and hay land are usually rented at a lower cash value than on other one-third share rented farms. In a few of these cases the landlord receives two-fifths of the corn and one-third of the other crops.

In Spink County, S. Dak., under this system the corn is frequently taken by the landlord at the farm. On 60 per cent of the farms rented for one-third share visited in Barnes County, N. Dak., the tenant delivered the grain at the elevator, and on 40 per cent of them the landlord received it on the farm or paid the tenant for its delivery. On 90 per cent of the farms renting for one-third share that were visited in Renville County, Minn., the tenant delivered the landlord's part of the grain at the elevator, and on 10 per cent of them the landlord either received it on the farm or paid the tenant for hauling it to the elevator. On all of the farms rented for one-third share visited in North Dakota the tenant secured land free of charge, in lieu of summer fallow, for an intertilled crop such as corn or potatoes and also for millet.

ONE-HALF SHARE.

When the tenant gives half the crop as rent, the landlord, in addition to what he furnishes under the one-third share system, supplies all the small grain seed, pays half the thrashing machine bill and sometimes pays for half the twine, and receives half the small grain delivered at the elevators. The tenant's obligations under this system differ from those under which he gives one-third only in regard to the supply of grain seed and to the thrashing and twine bills. Where land is rented for half the wheat, corn ground and sometimes ground for other grain is farmed for one-third of the crop, delivered.

EXCEPTIONS.

On the farms visited in Barton County, Kans., which rented for a half share, the spring crops, generally of comparatively small acreage, were usually produced on the one-third share rent basis. In Spink County, S. D., where the chief crop is wheat, the small acreage in corn is divided on the one-third and two-thirds basis, and the landlord gets his part of the crop in the crib, though the landlord may get half the corn crop by gathering the half at his own expense. On 14 per cent of the South Dakota share-rented farms corn land is paid for in cash at from $2 to $3 per acre, and on 2 per cent of them the tenant has corn land free.

On about two-thirds of the farms renting for one-half share in the North Dakota area, the landlord receives his half of the small grain on the farm or pays for its delivery, and on one-third of them the tenant delivers the grain free of charge to the landlord. In the North Dakota area where land is rented for a share of the crop, the tenant is usually given land free for millet or an intertilled crop, in lieu of summer fallow.

On half of the half-share rented farms visited in the Minnesota area the grain is delivered at the elevator, and on the other half it is either delivered on the farm or the landlord pays for its delivery. In the Minnesota area, most of the landlords receive but one-third of the corn, or the tenant pays cash for corn land at the rate of from $3 to $4 per acre. Here, also, instead of sharing the thrashing machine bill equally, the cost per bushel is sometimes shared so that the landlord pays one cent per bushel less than the tenant pays.

TWO-FIFTHS SHARE.

If the landlord receives two-fifths of the crop, both landlord and tenant contribute the same as under the system in which he receives one-third, although instead of getting one-third of the crop delivered, he gets two-fifths of it delivered. It will be noted from Table I that none of the farms visited in North or South Dakota are rented under this system.

The only exception found to the custom of delivering the landlord's grain in the case of any of the farms renting for two-fifths share that were visited, was in one instance in Minnesota, where the landlord received his corn on the farm.

ONE-HALF SHARE OF BOTH CROPS AND STOCK.

When the crops and stock are divided equally between the landlord and tenant, the landlord, in addition to what he contributes under the system in which he receives one-third, owns half the productive stock except poultry, and bears half the general farm expenses except those for labor and repairs to machinery; while the tenant supplies all the labor, owns all the work stock and farm machinery, keeps the machinery in repair, and owns half the productive stock. Under this system each of the contracting parties gets one-half of all farm sales except those from poultry or work stock, all of which go to the tenant. When farms are rented for a share of crops and stock, the lease provides whether the tenant's work stock may or may not be fed from the grain and hay owned in common and fed to the other stock.

On the farms visited no exceptions were found to the method of renting for half share of crop and stock, as outlined here.

TWO-THIRDS SHARE.

Under the renting system, according to which the landlord receives two-thirds of the crops and which, as will be seen from Table I, was found only on a few farms in Kansas, the landlord furnishes everything but the man labor, that being the tenant's only contribution. Under this system the tenant receives one-third of the grain only, while the landlord receives two-thirds of the proceeds from the sale of grain and all proceeds from the sale of stock.

THE CASH-RENT SYSTEM.

A few of the farms in each locality, except in the North Dakota area, were found to be rented for cash. In the Kansas area a quarter section rented for from $500 to $600 cash per year. On cash-rented farms with considerable alfalfa the tenants were satisfied, but on the farms without this crop they intended to give up their leases.

In the Nebraska area the average price paid for cash-rented farms was $3.67 per acre, including crop land, farmstead, hay, pasture, and waste. In the South Dakota area a few farms were found renting for cash at from $1.50 to $3 per acre for the entire farm, and in the Minnesota area 15 per cent of the tenant farmers paid cash rent. The rent there varied from $2 to $6.25 per acre for the entire farm.

CONDITIONS OCCURRING IN ALL SYSTEMS.

In general, under all of these systems of renting the landlord furnishes land, buildings, and grass seed, and pays the real-estate tax. He also supplies material for the repair of buildings and fences, and usually employs any skilled labor needed for making repairs. In all of these localities, however, land was frequently rented without buildings, and on some of the Nebraska farms visited the tenant owned all the farm structures and fences except the dwelling, the barn, and the windmill. On the share-rented farms visited in the Nebraska area the tenant sometimes paid a part or all of the real-estate tax.

Under all of these share-rent systems, except the one according to which both crop and stock receipts are divided and the landlord gets two-thirds of the crop, all productive stock is owned by the tenant, who gets all the income derived therefrom. However, the amount of such stock is too frequently limited by his acreage of pasture and hay land, by the amount of corn or rough feed he is allowed to grow, and by the shelter that is provided for such stock.

On the share-rented farms the use of hay land was usually paid for in cash, but was sometimes given free to the tenant; frequently it was rented for a share of the crop, and in some cases there was no hay land on the farm. Pasture was sometimes free to the tenant, but in many cases was paid for in cash. Sometimes the farm pasture was used in common by both landlord and tenant, and in some cases there was no pasture.

MINOR FACTORS CONCERNED IN RENTING OF FARMS.

Several minor factors not heretofore emphasized but exerting an important influence in the relation of landlord to tenant are concerned in the renting of farms. Among these are the terms for securing pasture and hay lands by the tenant, the distance from the farm to market, the value of the land, and the value of the farm buildings.

HOW THE TENANT OBTAINS PASTURE ON SHARE-RENTED FARMS.

In the localities in which this investigation was made tenants obtain pasture on share-rented farms in several ways, as can be seen from Table II.

TABLE II.—*Comparison of terms of renting pasture lands.*

Locality.	Average cash rent per acre for pasture.	Methods of procuring pasture.				
		Pasture free.	Pasture used in common.	Cash rent paid for pasture.	Farms without pasture.	Total.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Kansas: Barton County	$1.25	40	8	34	18	100
Nebraska: Clay County	2.60	7	3	80	10	100
South Dakota: Spink County	2.20	26	11	48	15	100
North Dakota: Barnes County	.92	35	10	5 [a] 30	20	100
Minnesota: Renville County	2.38	7	7	75 [a] 3	8	100

[a] These percentages of the tenants in the North Dakota and Minnesota areas secured pasture in return for working out the farm road tax.

Much of the pasture in all the areas visited was free to the tenant, but in a large percentage of cases the pasture was either paid for in cash or the tenant worked the farm road tax for it. Relatively more farms were without pasture in the counties visited in North Dakota and Kansas than in the other areas. This lack of pasture may have influenced the landlords to give the tenants in these States a few acres for forage crops free of rent, as this was done more frequently here than in other areas visited.

HOW TENANTS OBTAIN HAY LAND ON SHARE-RENTED FARMS.

Some tenants in each of these localities procure their hay land free of charge, others rent for cash, and still others on shares. Table III shows the comparative methods of renting hay land and the price per acre where cash is paid.

TABLE III.—*Comparative methods of renting hay lands.*

Locality.	Tenants getting free hay land.	Tenants paying cash for hay land.	Tenants having no hay land.	Tenants giving— One-half in stack.	Tenants giving— One-third in stack.	Tenants giving— One-third delivered.	Average cash paid for hay land.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Kansas: Barton County	11	10	44	25	10	0	a $8.50; b 2.50
Nebraska: Clay County	5	59	11	21	2	2	c 4.20; b 2.80
South Dakota: Spink County	4	53	29	12	2	0	c 4.00; b 2.25
North Dakota: Barnes County	40	d 5; 20	15	18	2	0	.95
Minnesota: Renville County	10	53; d 3	9	10	12	3	2.70

a Alfalfa.
b Wild.
c Tame.
d These percentages of the tenants in the North Dakota and Minnesota areas secure hay land in return for working out the farm road tax.

Many of the Kansas and South Dakota tenant farms are deficient in hay land. Tenants in the Kansas area frequently pay as much as $10 an acre for alfalfa hay land located off the farm, alfalfa lands commanding a higher rent than any other farm land in that locality. The deficiency of hay land on the farms in the South Dakota area was supplied by wild hay from the school lands which are still abundant there.

PASTURING WHEAT AND THE DIVISION OF STALKS AND STRAW.

PASTURING WHEAT.

In the Kansas and Nebraska areas where winter wheat is grown, the tenant is sometimes allowed to pasture wheat at his discretion, it being understood that it will not be pastured either in very dry or very wet weather. In many instances the pasturing of grain is forbidden in the contract.

STALKS.

The cornstalks are nearly always the property of the tenant, but he may not have the stock to make proper use of them, and that use is often limited by the lack of fencing. In the Minnesota area, the only one of the localities visited where wheat was not the predominant crop, more corn is raised by the average tenant, who keeps more stock and makes more effective use of farm forage.

STRAW.

The tenant with rare exceptions has the use of all the straw produced on these farms. He generally feeds most of the oat straw, uses some of the wheat straw for bedding, some for mulching potatoes or young trees, and may scatter some of it on the land, but except in the Minnesota area most of the wheat straw is burned.

DISTANCE TO MARKET.

In the Kansas area the average distance of the farms visited from market is 4.5 miles; in the Nebraska area 3.6 miles; in the South Dakota area 4.4 miles; in the North Dakota area 5 miles; and in the Minnesota area 5.6 miles. Very few of the farms are more than 9 miles from the market, and the share of the crop given in no case appears to differ on account of the distance to market, except that the average distance to market of the farms renting for two-fifths share is less than the average distance of those renting for one-third share in all the localities where these proportions are in vogue.

Free pasture as well as cheaper hay land was more frequently given to the tenants farthest from market, and tenants farther from market were more frequently paid for delivering the landlords' grain than were those near the market.

VALUE OF LAND AND BUILDINGS.

It was not always apparent in this investigation that the value of land or of the buildings were factors in the determination of the share-rent paid. In all the localities visited where farms were rented for both one-third and two-fifths share, the land was of the greater value on those renting for the greater share. In Kansas and Minnesota the farms renting for two-fifths of the crops had buildings of much higher average value than those of the other farms, but in the Nebraska area the farms renting for two-fifths of the crops had outbuildings of less value than those renting for one-third. The comparative values of land and buildings and the average farm areas are shown in Table IV.

TABLE IV.—*Comparative value of land and buildings on the farms visited.*

Locality.	Average acres and estimated values.									
	Acres per farm.	Value per acre.			Value of dwellings.			Value of outbuildings.		
		All farms.	Farms renting for one-third share.	Farms renting for two-fifths share.	All farms.	Farms renting for one-third share.	Farms renting for two-fifths share.	All farms.	Farms renting for one-third share.	Farms renting for two-fifths share.
Kansas: Barton County	336	$80	$73	$83	$1,266	$1,013	$2,133	$925	$830	$1,100
Nebraska: Clay County	225	115	113	113	1,026	1,022	1,027	730	726	545
South Dakota: Spink County	427	65	66	....	844	830	....	744	736	....
North Dakota: Barnes County	489	60	46	....	1,155	1,233	....	1,194	1,300	....
Minnesota: Renville County	202	115	145	145	981	660	979	909	950	964

SHARE RENT OF LAND WITHOUT BUILDINGS.

Some of the tenants in each area visited had found their farms too small and were renting additional land without buildings. Some farmers interviewed were owners of farms too small for their needs, and rented outside land, not necessarily provided with buildings.

In the Kansas area 25 per cent of the records taken related to such farmers. In the latter case the lack of improvements did not affect the share of the crop given for the use of the land. In none of the other regions visited did such a large percentage of the tenants rent additional land without buildings, and when renting such land they usually gave a smaller share of the crop, or received hay and pasture either free or for less than their actual value.

LEASES.

In both the Kansas and Nebraska areas there were more oral than written leases; in South Dakota written and oral leases were about of equal frequency; but in North Dakota and in Minnesota most leases were written. As seen from Table V, there was a greater percentage of parent landlords in Kansas, Nebraska, and South Dakota than in the other States. The fact that leases on farms rented by parent landlords are nearly always oral accounts in part for the preponderance of the oral lease in these States. Landlords in general desire experience with a tenant before entrusting him with their farms without the written contract. This fact can also be seen from Table V, where it is shown that tenants on farms for the first year are usually under a written contract.

TABLE V.—*Comparative data concerning leases and the lease period.*

Locality.	Proportion of leases—						
	Written.	Verbal.	Yearly.	For longer time than one year.	Given by parent landlords.	For first year on farm—	
						Written.	Verbal.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Kansas: Barton County	25	75	90	10	25	44	56
Nebraska: Clay County	40	60	97	3	25	53	47
South Dakota: Spink County	48	52	95	5	20	100	0
North Dakota: Barnes County	60	40	73	27	16	92	8
Minnesota: Renville County	59	41	75	25	15	76	24

THE LEASE YEAR.

In the Kansas area visited the chief crop (wheat) is usually thrashed and disposed of by August 1, and the lease year usually begins on that date. Eighty-eight per cent of the tenants visited in the Kansas area stated that their lease year begins August 1 and only 12 per cent that it begins in the spring. In the Nebraska area the lease year begins in the spring, the period on nearly all tenant farms running from March to March. In the South Dakota area, with 27 per cent of the tenants the leases begin in the spring, usually March 1, while with 73 per cent the leases begin in the fall, usually on October 1. In the North Dakota area 54 per cent of the leases begin in the spring and 46 per cent in the fall.

In Renville County, Minn., about half of the leases on the farms visited begin in the spring (March or April), while half of them begin in the fall (October or November). A few of the leases here begin in the spring and end in the fall or winter, or vice versa, the lease period in these cases being for more than one year.

TENANTS' PREFERENCES AND PROSPECTS.

PREFERENCE AS TO LEASE PERIOD AND SHARE OR CASH RENT TO BE PAID.

As seen from Table VI, from 60 to 86 per cent of the tenants in the localities visited prefer the long lease, and from 85 to 100 per cent prefer share to cash renting.

TABLE VI.—*Tenants' preferences as to length of lease and cash or share rent.*

Locality.	Proportion of tenants—					
	Who prefer—		Indifferent as to length of lease.	Who prefer—		Indifferent as to how paid.
	The long lease (5 to 10 years).	The short lease.		Share rent.	Cash rent.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Kansas: Barton County	70	20	10	96	1	3
Nebraska: Clay County	86	2	12	93	2	5
South Dakota: Spink County	77	3	20	96	0	4
North Dakota: Barnes County	60	20	20	100	0	0
Minnesota: Renville County	70	23	7	85	15	0

THE LANDLORD'S OPINION AS TO THE LONG LEASE.

Landlords were seldom questioned in any of the areas visited, but some expressions were obtained from them as to the proper lease period. The following quotation from a letter of one of the owners of a number of rented farms in North Dakota shows the general attitude of the landlord toward the lease period:

It is our custom to make annual leases only and in this we differ from many authorities who think it better to lease for a term of years. Our rule is "Give the old tenant the first chance at the farm if his work has been good." Under this plan the tenant knows he can remain on the farm if his record is good, and it is up to him to do his work so that he will not be displaced.

We aim to keep the buildings in good condition of repair. This is a simple matter, but one which seems to keep the feminine end of the family in a contented frame of mind. We try to provide facilities for live stock, poultry, garden, etc., in which we are not directly interested but which help the tenant in a financial way.

PROSPECTIVE OWNERSHIP BY TENANTS.

In each of the localities visited there were many tenants who owned some land. In most cases this land was situated in sections where the price of land was lower than where the tenant was located. As seen from Table VII, tenants who had bought in their present localities purchased in an average time of from 5.5 years, in Minnesota, to 9.9 years, in Nebraska, after they had started renting.

TABLE VII.—*Prospective ownership by tenants.*

Locality.	Years rented before buying.	Tenants who own some land.	Nonowners who expect to own.	Tenants who think they could pay half value of a farm in 15 years.
		Per cent.	*Per cent.*	*Per cent.*
Kansas: Barton County	6.2	40	96	60
Nebraska: Clay County	9.9	33	85	24
South Dakota: Spink County	8.3	23	90	60
North Dakota: Barnes County	6.9	30	92	45
Minnesota: Renville County	5.5	27	96	30

It will be seen from the table that in only two of the localities visited, namely, Kansas and South Dakota, do a majority of the tenants think, in view of their past experience, that they can become owners in their present localities within 15 years. The owners renting additional land in all these localities, while usually admitting that a farm is not now so readily acquired by a tenant as when they bought, think that they could still become owners were they starting to rent. From 85 to 96 per cent of the nonowners expect to own farms, if not in their present localities, then some place where land costs less.

BELIEF OF TENANTS AS TO TREND OF RENTS.

Each tenant was asked to express his opinion as to whether rents in his locality were increasing or not. In the Kansas area, 70 per cent of the tenants thought that rents were increasing and 30 per cent that they were not; in the Nebraska area, 74 per cent thought rents were increasing and 26 per cent that they were not; in the South Dakota area, the tenants were equally divided in opinion with regard to the increase of rent; in the North Dakota area, 34 per cent of the tenants thought rents were increasing, while 66 per cent thought they were stationary; and in the Minnesota area, 85 per cent of the tenants thought that rents were increasing, while 15 per cent thought they were not.

Tenants who thought rents were increasing claimed that where land was rented for cash a higher rate was asked per acre; that share rent, instead of being one-third as formerly, was getting to be two-fifths; that where the share paid remained unchanged there were fewer instances of tenants getting pasture and hay land free; and that where cash was paid for pasture and hay land it was commanding a higher price per acre.

PROBABLE INCREASE IN TENANCY IN AREAS VISITED.

Table VIII shows the increase of tenancy in these areas from 1890 to 1910:

TABLE VIII.—*Increase of tenancy in the areas investigated.*

	Proportion of tenants among farmers.		
	1890	1900	1910
	Per cent.	*Per cent.*	*Per cent.*
Kansas: Barton County	21.0	25.3	38.0
Nebraska: Clay County	33.4	40.7	49.8
South Dakota: Spink County	20.0	26.8	43.4
North Dakota: Barnes County	8.2	7.5	31.4
Minnesota: Renville County	9.4	21.6	29.0

It seems probable that the increase in tenancy in these regions will continue at least for some years yet. The average size of the farms operated by tenants as found in the investigation varied from 202 acres in the Minnesota area to 489 acres in the North Dakota area. The income from such a farm is sufficient to maintain its owner without much personal labor on his part. He is therefore likely to retire and rent his land. Because of the increased cost of a farm, tenants find it more difficult to attain the status of owner, and in the future will probably remain tenants for a longer period than has been the case in the past. This tendency seems to be general in the regions in which the economic farm unit is equivalent to a modest fortune.

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER August 10, 1920

GENERIC CLASSIFICATION OF THE HEMIPTEROUS FAMILY APHIDIDAE

By

A. C. BAKER, Entomologist
Deciduous Fruit Insect Investigations

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JOHN R. MOHLER, Chief

Washington, D. C. May 26, 1921

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By

F. W. FARLEY and S. W. GREENE
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WM. A. TAYLOR, Chief

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By

FREDERICK V. RAND, Assistant Pathologist, and ELLA M. A. ENLOWS, formerly Assistant Pathologist
Laboratory of Plant Pathology

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THOMAS H. MacDONALD, Chief

Washington, D. C. | PROFESSIONAL PAPER | August 25, 1920

SPILLWAYS FOR RESERVOIRS AND CANALS

By

A. T. MITCHELSON, Senior Irrigation Engineer

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NOTATION.

Unless otherwise noted, the various symbols used throughout this publication will have the following significance:

H —Effective head, in feet.

H_0—Loss of head at entrance of siphon, in feet.

H_1—Loss of head due to friction in siphon, in feet.

H_2—Loss of head due to sudden enlargements in siphon, in feet.

H_3—Loss of head due to contractions in siphon, in feet.

H_4—Loss of head due to bends in siphon, in feet.

H_v—Velocity head necessary to create velocity at the entrance, in feet.

V —Velocity, at throat of siphon unless otherwise noted, in feet per second.

A —Area of cross section treated, in square feet.

k —A coefficient in the formula for siphon discharge, ranging from 0.50 to 0.80 and usually assumed according to the materials of construction and the form of the siphon.

g —Acceleration of velocity due to gravity, $=32.16$ feet per second per second.

C —A coefficient, in the formula for weir discharge varying from 2.5 to 4.5 and determined from experiments on small model weir dams under low heads.

p —Height of weir in feet above the bed just upstream from weir and applied only in the Bazin formula.

h —Head, in feet corresponding to velocity of approach.

L —Length of weir crest, in feet.

Q —Quantity of discharge, in cubic feet per second.

UNITED STATES DEPARTMENT OF AGRICULTURE

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THOS. H. MACDONALD, Chief

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